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METALLURGIA

THE BRITISH JOURNAL OF METALS

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PRINCIPAL CONTENTS IN THIS ISSUE:

	Page
Improved Electro-Magnetic Apparatus for the Detection of Cracks in Welded Steel Tubular Structures. *The general principles of electro-magnetic crack detection are given, and an improved apparatus described which is giving satisfactory service in the testing of welded steel tubular structures.*	163–165
Correspondence .. .. *Some methods for the Fabrication of Light Alloys.*	165–166
Magnesium from Brucite	167–168
The Roberts-Austen Centenary Lecture. By S. W. Smith, C.B.E., D.Sc., A.R.S.M., F.R.S. .. .. *Sir William Chandler Roberts-Austen conducted a notable series of researches for the Alloys Research Committee of the Institution of Mechanical Engineers; he was president of the Iron and Steel Institute in 1899–1901, and his name is perpetuated in ferrous metallurgy by the the term "austenite." His work in both ferrous and non-ferrous metallurgy stamped him as a truly great metallurgist, and in this lecture Dr. Smith not only describes his work, but deals with the man and his outstanding qualities.*	169–177
Drawing of Sir William C. Roberts-Austen. By Arnold Radcliffe ..	169
Practical Aspects of Industrial Furnace Insulation. By J. W. Dawson .. *The proper application of high-temperature insulating firebrick provides an easy and effective method of economising in fuel; in addition, however, new economies and advantages are introduced, the most important of which is the saving of time. Hot-face insulation is discussed.*	177–180
A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts .. .. *This report constitutes a summary of data resulting from the examination of German and Italian aircraft parts. In this, the final of the series, is presented a summary of the results of investigations on a number of miscellaneous components, including a pipe from an exhaust system, control chains, gun mounting parts, and bomb-release mechanisms.*	181–184
Powder Metallurgy—Its Products and Their Applications. By W. D. Jones, M.Eng., Ph.D. .. .. *The popularity of powder metallurgy depends upon its application in the manufacture of metal parts not easily made by other processes.*	185–187
Rationalisation in Iron Foundries. Part II.—Contd. Application of Principles. By F. L. Meyenberg, M.I.Mech.E. .. .. *Further reference is made to analysis of time, and additions for lost time, and for falling off in the rate of working are considered.*	188–190
The Behaviour of S.82 about its Critical Range and the Effect on Annealing Practice. By C. Wilshaw .. .. *The fact that nickel-chrome steels, when heated to gradually rising temperatures and cooled in water, show progressive hardening at temperatures below the beginning of AC_1 is known, but the author draws attention to some interesting experiments.*	191–194
Magnesium and Its Production .. .. *The demands for magnesium-base alloys has caused phenomenal expansion of the magnesium-metal industry, and this article surveys some developments in the raw materials used and in the processes employed.*	195–198
The Positions of the Carbon Atoms in Martensite. By N. J. Petch, B.Sc., B.Met. .. .. *As a result of a study of the subject, the author concludes that the carbon atoms are at the mid-points of the long edges of the martensite tetragonal cell and at the centres of the faces perpendicular to them.*	199–201
The Development of Carbide-Tipped Tools	201–202
The Problem of Copper and Galvanised Iron in the same Water System. By L. Kentworthy, M.Sc., A.R.C.S. *Premature failure of galvanised hot-water tanks connected to copper circulating pipes in domestic systems led to laboratory investigation and to an extensive examination of service installations.*	203–204

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METALLURGIA

THE BRITISH JOURNAL OF METALS.
INCORPORATING "THE METALLURGICAL ENGINEER."

MARCH, 1943 VOL. XXVII. No. 161

Improved Electro-Magnetic Apparatus for the Detection of Cracks in Welded Steel Tubular Structures

Non-destructive tests have long been used for the detection of cracks, but a standard equipment and technique do not appear to have been developed for testing the welds of tubular structures. The general principles of electro-magnetic crack detection are given and an improved apparatus described which is giving satisfactory service in the testing of steel tubular structures.

HOW to ensure the soundness of welded steel tubular structures, particularly those which are built into airframes as engine nacelles, has always been something of a problem to the fabricators of the structures, to aircraft constructors, and to the inspecting authorities. Not only has it been almost impossible to assess the standard of workmanship of any particular welder without destroying a certain percentage of the articles produced, but hair-line cracks might be present which could not be discerned upon visual inspection, but which could develop in service with very serious consequences.

A number of devices, mostly of an electro-magnetic character, have been used for the detection of cracks during the past decade. A standard equipment and technique does not, however, appear to have been developed, and individual companies have followed their own ideas and methods with varying degrees of success.

The vastly extended use of welded tubular steel structures in aircraft in time of war, together with restrictions upon the types of steel available, has made it highly desirable that the detection of cracks in welded structures should be placed upon a sound basis as soon as possible.

Before describing a form of apparatus recently produced, it may be advisable to state very briefly the general principles involved in electro-magnetic crack detection.

When a magnetic field is created in a ferro-magnetic material, any interruption of the lines of force, such as that caused by a crack or a non-metallic inclusion, will force the flux to bridge the gap externally. The existence of this leakage of magnetic flux may be revealed by the use of magnetic detecting "ink." It has been found that to make certain of detecting such discontinuities, the lines of force must be created in a direction substantially at right angles to the suspected faults. It is therefore clearly necessary to provide two separate magnetic fields, so that lines of force are produced in two directions, at an angle of 90°—e.g., longitudinal and transverse to the article being tested. These two fields may be created together or separately as may be convenient. Furthermore, the flux may be produced either by direct or by alternating current. The flux of constant magnitude produced by direct current will, in general, tend to reveal subcutaneous defects at a greater depth than flux produced by alternating current. This is due to the well-known "skin effect" of alternating current whereby, depending upon the frequency of the supply, the outer layers of the material are penetrated less by the flux as the frequency of the supply is increased. The use of direct current may, however, be troublesome, since the article becomes magnetised permanently and needs complete demagnetisation. Further, the heavy currents required (normally some hundreds of amperes) are more conveniently obtained by using step-down transformers on alternating current mains supply. A motor generator set or heavy duty accumulators would be necessary if direct current were employed. For these reasons, alternating current is to be preferred for magnetisation.

Experimental work has indicated that the following conditions must be satisfied if maximum sensitivity in the detection of cracks is to be obtained :—

1. The welded structure should be painted with a flat

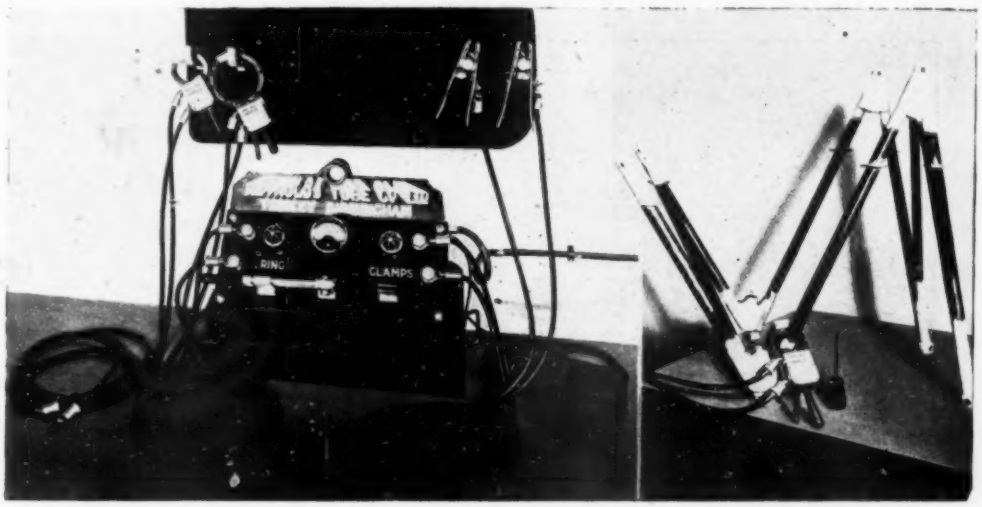


Fig. 1. — Showing the improved electro-magnetic apparatus for the detection of cracks in welded steel tubular structures. An application is shown on the right.

white paint prior to the application of the magnetic ink.

2. The magnetising current should be not less than 400 amps. and preferably 600 amps.

3. Lines of force should be produced in two directions at right angles—e.g., longtitudinal and circumferential to the tube being tested.

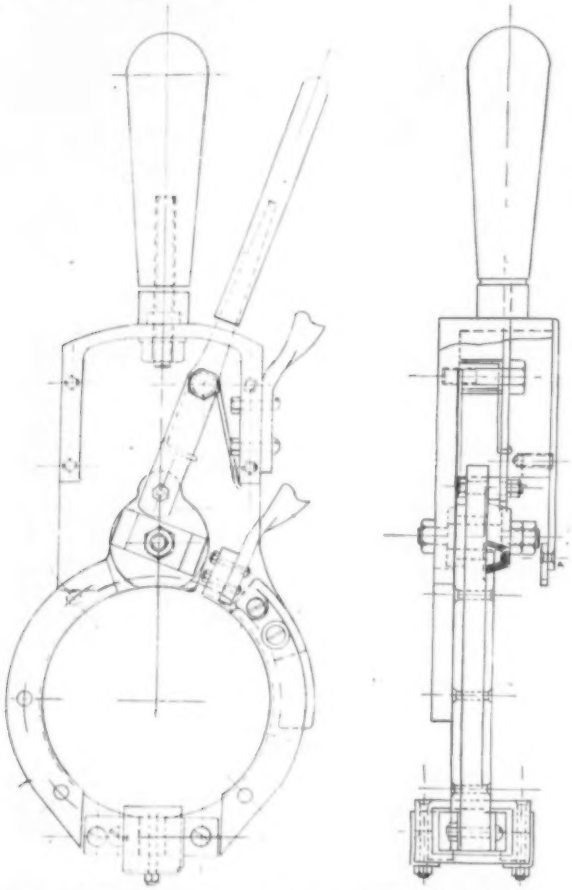


Fig. 2.—Line drawing showing construction of ring clamp for the longitudinal test.

Having established the principal conditions necessary to give the desired results, the next step was to design equipment suitable for operation by inexperienced workers. It had to be borne in mind that the use of very heavy currents meant that the operators would run the risk of severe burns or even blindness unless full automatic protection were provided.

Apparatus designed by the electrical engineer of Reynolds Tube Co., Ltd., is illustrated in Fig. 1. A step-down transformer, conveniently mounted in the metal container shown in the photograph, has an output of 600 amps. at 6 volts, using 230-volt alternating current mains supply.

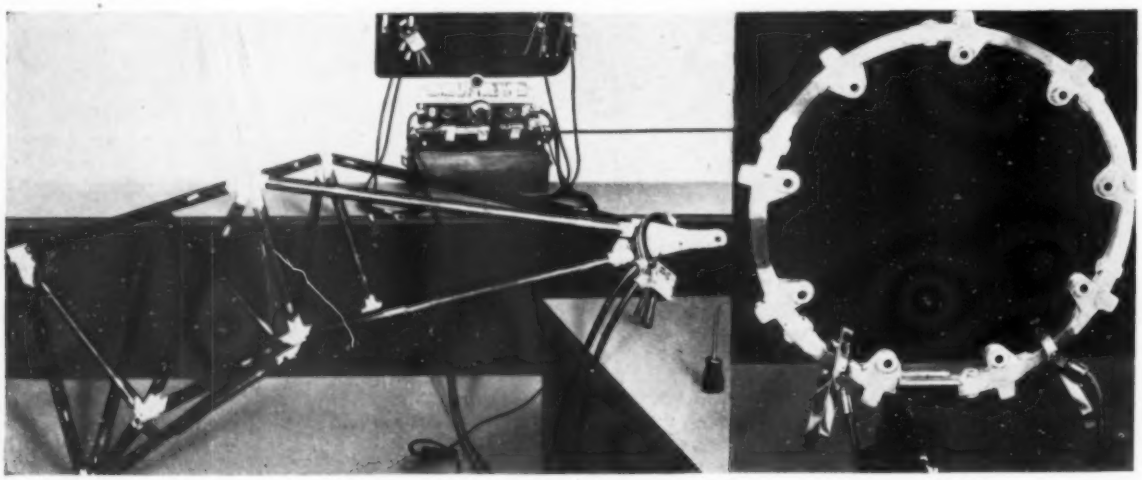
Before commencing work, the operator closes a switch located at the bottom right-hand side of the metal container, allowing alternating current to pass from the mains to the apparatus. A red pilot light at the top of the panel is then illuminated, indicating that the apparatus is alive. A single-pole double-throw switch enables the use either of the clamps for circumferential tests or of a single loop induction ring for longitudinal tests. This change-over switch is in the secondary circuit of the transformer and carries a heavy current. For this reason it is protected by electrical interlocking with the transformer primary circuit. Withdrawal of the moving blade from either of its associated stationary contacts enables a metal plunger to rise and open a switch in the primary circuit. One of these plungers may be seen protruding through the panel in the illustrations. The primary circuit is broken before the blade finally leaves the contacts, so that no current is passing when the secondary circuit is broken. Similarly, the blade must make contact with its associated contacts before the primary circuit can be re-established by depression of one of the metal plungers.

Additional control is provided by a contactor switch on the primary side of the transformer. The contactor closes, establishing the circuit, when a foot-operated switch on the floor is depressed. Two green pilot lights, one on each side of the panel, indicate whether current is passing through the clamps or through the ring, depending upon the position of the S.P.D.T. switch. These pilot lights are in circuit with the contactor, so that if the contacts should remain closed after the operator has allowed the foot switch to open, one of the green pilot lights remains illuminated. Warning is thus given that the contactor has not operated, due to welding of the contacts or some other mechanical defects.

The construction of the clamps for the circumferential tests may be clearly seen from the illustrations, and calls for no special comment.

The construction of the ring clamp for the longitudinal test is shown in Fig. 2. It is constructed of light alloy for convenience in handling and consists essentially of a ring formed by two semi-circular jaws. One of these is permanently fixed to the handle, but the other is pivoted on the hand-grip. A trigger attached to the hand-grip actuates the movable jaw and is spring loaded to ensure that the contacts normally remain closed. The pivot is surrounded by a box-like structure to which are attached the electric cables feeding each jaw. Supply to the movable jaw is through a

Fig. 3.—Showing some further applications of the apparatus in testing welded tubular structures for airframes.



flexible metal brush on the pivot pin. The handle is insulated from both of the jaws. On the open end of the fixed jaw a hollow shield is mounted. This is made from insulating and heat-resisting material, and completely surrounds the contacts when the jaws are closed. If an arc should be forced through inadvertent opening of the contacts while a heavy current is passing, it is confined by the shield and the risk of injury to the operator or damage to the work being tested is thus practically eliminated. The semi-circular jaws themselves are also insulated to prevent short circuit across the work while the test is being made.

The ring clamp is covered by Provisional Patent No. 14457/42, but, in view of its value to the national war effort, it is not proposed to reserve its use. Provided that the Patent is suitably acknowledged, the patentees are willing to give permission for the use of the apparatus without payment or royalty. The photographs reproduced show the apparatus in use testing the welds on various types of tubular structures.

Magnetic detecting "ink" is used in both the tests described.

The apparatus has now been used by the patentees for some months, and has been found to be very sensitive in the detection of hair-line cracks or other faults. Nevertheless, it is of robust construction, and the safety features incorporated reduce the risk to the operator to negligible proportions.

Correspondence

Some Methods for the Fabrication of Light Alloys

The Editor, METALLURGIA.

Dear Sir,

I have read with considerable interest the article by Dr. E. G. West, in your February issue on the above subject. The developments he refers to apply equally well, of course, to sheet-metal components generally, and are not confined to light alloys apart from, perhaps, his reference to extrusions and finishing methods.

The main purpose of this letter, however, is to deal with his remarks in connection with "Pressing with Rubber," wherein some statements and recommendations are made, which, if followed by future users of the process, will lead to disappointment and failure to obtain full benefit from its use. The recommendation to use softer rubbers of 50 Shore hardness or lower will lead to difficulties in certain cases where it is desired to form convex flanges at the lower pressures, owing to premature and excessive buckling.

As a result of research work carried out, in this country and in America, the tendency is to go to pressures greater than 0·75 tons/sq. in. up to 1·5 tons/sq. in., and to use rubber with a Shore hardness of 65–70 mainly for the following reasons:—

1. In the forming of convex flanges involving shrinking, the use of the harder rubber and higher pressure prevents premature buckling and wrinkling of the flange by providing a suitable backing up of the flange.

2. Higher pressure intensities reduce the spring-back for a given thickness of material and radius of bend.

3. Higher pressures make it possible to form thicker and stronger materials for shapes involving comparatively small flange radii.

4. The harder rubber pads have a much greater life than the softer pads owing to the smaller amount of flow which occurs.

5. In the drawing of metal parts, it is a better practice to use auxiliary rubber pads to minimise distortion of the main pad, and here it is admittedly better to use a soft rubber for the auxiliary pad only.

6. If a soft rubber is used in forming flanges, there is a tendency for the first deformations of the rubber to get behind the metal and against the block and so prevent the efficient flanging of the part.

7. In using the softer rubber in the forming of some parts, it has been necessary for the tools to have integral restraining walls to intensify the rubber pressure at certain points, and the fact that the use of these walls involve considerable work in making the tools tends to defeat the main effect of the process, which is to enable tooling to be cheaper in cost and to be carried out in the minimum of time.

I am also of the opinion that his statement, "Hence a 500-ton press with soft rubber is capable of doing the work which would require a 1,500-ton press with hard rubber," is definitely wrong and misleading. Of course, there will be certain jobs which may be done on either press, but it is extremely doubtful whether convex or concave flanges of small radii could be formed in D.T.D. 390 material of thick gauges, using a rubber of 50 Shore hardness or less, and a press with an intensity of pressure of 0·25 tons/sq. in.

With regard to the section dealing with joining, he states that "Blind riveting has always been troublesome," a statement with which I cannot agree. For many years there has been in existence in this country a perfectly satisfactory and trouble-free system of blind riveting, known as "Pop Riveting," and these rivets are used to-day at the rate of "millions a week." The explosive rivets, referred to in the article, whilst being interesting or novel, are not really satisfactory, owing to their inability to fill the hole tightly, especially if the hole is slightly oversize, as often occurs under production conditions, and consequently they do not stand up very well under vibration.—Yours faithfully,

R. F. TAYLOR.

Research Department,
A. V. Roe and Co., Ltd.
February 26, 1943.

The Editor, METALLURGIA.

Dear Sir,

I am indebted to you for the opportunity of replying to Mr. R. F. Taylor's letter, commenting on my contribution to the February issue. I did not intend to do more than summarise a few of the methods of fabrication with which I have had direct contact during the immediate past, and I certainly do not claim that the processes mentioned are all applicable exclusively to the light metals. Actually, I confined my remarks to the wrought-aluminium alloys, and all my statements were based on the experience of many users of these processes.

Clearly Mr. Taylor and his colleagues have accumulated a vast quantity of data on rubber pressing, riveting and other operations, and everyone would be grateful if a full account of production and experimental methods used for the world's best bomber could be prepared. Perhaps you, Mr. Editor, might be able to prevail on the "powers that be" to allow this to be done for the benefit of all other fabricators.

I was careful to point out at the bottom of page 139 that "finality has not been reached" on the question of rubber hardness or pressures required, and also gave a number of references from which readers could obtain fuller details. Greater pressure is undoubtedly necessary for heavy gauges, especially in the higher strength alloys, but the fact remains that a great proportion of current production can be more efficiently obtained by using soft rubber. In one works, for example, an increase of 30% resulted from changing to softer rubber on a large hydraulic press.

Regarding the life of rubber pads: Sufficient data is not yet available, in my opinion, to justify a definite statement as to the number of components of a like shape and size which can be produced on pads of equal depth. The use of auxiliary pads is troublesome and delays loading

the table, but they are not extensively required with the softer types of rubber.

"Intensifiers" are often desirable, and generally the slight increase in tooling is fully justified by the higher output obtained. In many cases the intelligent arrangement of a number of tools on the platen allows them to provide mutual "intensification."

My statement that a 500-ton press with soft rubber was capable of doing work which required a 1,500-ton press, using hard rubber, was not "wrong" but a definite fact in more than one works.

On page 141, regarding blind riveting, explosive rivets were mentioned as "one of the most interesting ways of overcoming the difficulties"—I assumed that every reader would be familiar with "pop" rivets, and merely wished to draw attention to an alternative which, I consider, should be further investigated for certain jobs.

Space forbids a reply in greater detail, but I certainly found Mr. Taylor's remarks of great interest from many points of view, and hope the correspondence leads to further investigations into the various matters raised.

Yours truly,

E. G. WEST.

Birmingham.
March 13, 1943.

Drilling Deep Holes in Magnesium Alloys.

IT is generally recognised that deep holes can be satisfactorily drilled in magnesium alloys, but little information is available on the accuracy of the holes that are produced, the power that is required for drilling, or the best way in which to alter standard drills in order to improve their performance. Extensive experiments have recently been made, however, to determine which type of drills and drilling techniques are best suited for deep hole drilling in magnesium. The results of these experiments are described by Gilbert and Lennie.*

Drilling tests were made by drilling holes to a maximum depth of 10 in. During the drilling operation the torques and thrusts were graphically recorded, showing the operation of the drill as affected by the depth of hole. The formation and disposal of the chips were observed during the drilling process, and a further study made after drilling by cutting open the test-blocks and inspecting the holes for straightness, roundness, surface finish, and size. The variables which were independently tested for both the $\frac{5}{32}$ in. and $\frac{1}{2}$-in. diameter drills were:—

1. Cutting speed or revolutions per minute of the drill.
2. Feed, inches per revolution.
3. Design of the drill.
4. Effect of cutting fluids.

All tests were made on 2 × 10 × 12 in. chill-cast blocks of Dowmetal H alloy (6% aluminium, 3% zinc, 0·2% manganese, and remainder magnesium).

The authors conclude that there is a difference in the drilling action between drills of small ($\frac{5}{32}$ in.) and large ($\frac{1}{2}$ in.) diameter which requires different techniques of operation for each size range.

Helix Angles.—(*a*) For shallow holes, the helix angle should be in the range of 10° to 20° for both $\frac{5}{32}$-in. and $\frac{1}{2}$-in. drills, although higher helix angles can be used with a sacrifice in quality of the drilled hole.

(*b*) Deep holes, ordinarily considered as those having a depth of over five times the drill diameter, require the use of 40° to 45° helix angle drills for high-speed quality production. This range of helix angle is required in both the $\frac{5}{32}$-in. and $\frac{1}{2}$-in. drills.

Drill Pointing.—(*a*) The chisel-edge angle for $\frac{1}{2}$-in. drills should be in the range of 135° to 150° to ensure straight, accurate holes. Different angles result in spiralled and over sized holes. Heavy feeds require chisel-edge angles of approximately 150° to insure sufficient relief. For shallow holes, the chisel-edge angle may be 135° or smaller, but for good-quality deep holes it must be as recommended and accurately centred.

(*b*) The point angle may vary from 70° to 118° in drilling shallow holes, but for deep-hole drilling it should be restricted to the standard 118° angle. Smaller or larger angles result in out-of-round and inaccurate deep holes.

(*c*) Special drill points can be used to advantage in both shallow- and deep-hole drilling. For shallow holes, rounding the corners of the point will give holes nearer to size, and with better surface finish. Adding a spur point will pilot the drill, preventing a spiralled out-of-round hole. In deep-hole drilling, a spur point added to the 118° point angle will greatly improve the accuracy and surface finish.

Opening and Polishing Flutes.—In the drilling of shallow holes the opening and polishing of the drill flutes had little effect on the operation of the drills. This was true for both the $\frac{5}{32}$-in. and $\frac{1}{2}$-in. diam. drills. For deep-hole drilling with $\frac{5}{32}$-in. and $\frac{1}{2}$-in. drills, the increase in the flute space and improvement in the surface of the flutes aids in the removal of chips. This prevents high torques and rough surface finish due to jamming of the chips in the flutes. The effectiveness of polished flutes is more noticeable with the high-helix angle drills when drilling deep holes.

Feeds.—Feeds in the range of 0·004 in. to 0·040 in. per revolution can be used in drilling shallow holes with both both $\frac{5}{32}$ in. and $\frac{1}{2}$-in. diam. drills.

Deep-hole drilling requires the use of feeds of approximately 0·006 in. for $\frac{5}{32}$-in. drills and feeds from 0·009 in. to 0·021 in. for $\frac{1}{2}$-in. diam. drills. Heavy feeds reduce spiralling, but a feed of 0·014 in. was found to be optimum, considering all aspects of $\frac{1}{2}$-in. drills.

Chip Formation.—The feeds recommended in the preceding section produce the correct chip formation for ease in drilling deep holes in magnesium alloys. Smaller drills $\frac{5}{32}$ in. diam., require a straight ribbon-like chip which can follow the flutes, whereas larger drills, such as $\frac{1}{2}$-in. diam. require a broken, segmented chip which will fill and follow up the flutes without jamming. Any chip formation will function satisfactorily in drilling shallow holes.

Cutting Speeds.—For both the $\frac{5}{32}$-in. and $\frac{1}{2}$-in. drills, there was an improvement in surface finish of drilled holes with the use of higher speeds. Speeds of 80 and 180 fpm. proved to be best for $\frac{5}{32}$-in. and $\frac{1}{2}$-in. drills, respectively but these were limited by the equipment. The literature and commercial practice recommend from 300 to 2,000 fpm.

Cutting Fluids.—Cutting fluids of the types recommended for use on magnesium alloys help prevent packing of the chips and keep the work cool. Lighter-viscosity fluids work best in this operation.

* W. W. Gilbert and A. M. Lennie, *Mech. Eng.*, lxiv, 1942, pp. 877-887.

Gas Cyanization (Nitrocementation)

A GAS for simultaneous nitration and carbonisation (nitrocementation) must be rich in C and must contain at least 50% hydrocarbons. It is necessary that the cementation gas and the NH_3 be brought to the furnace in separate lines so that mixing takes place only after the gases are in the furnaces. Cyanide compounds are formed in the nitrocementation process. For this reason care must be taken that no gas leaks from the furnace into the surrounding working space. With a temperature increase from 600° to 830° and a retention period of 90 mins., or with a temperature of 830° and a period of cementation of 1—4 hours, the curve for the depth of saturation of the steel with C and N approaches a straight line. The nitrocementation process gives equally good results with pure C steel and with Cr–Mo and Cr–Mn–Mo steels.

N. F. Vyazmikov and A. A. Yurgenson, *Metallurg* 15, No. 7, 24-32 (1940) *Chem. Zentr.*, 1941, I, 455.

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Magnesium from Brucite

IT is remarkable how rapidly the metal magnesium has been developed in the past few years. The fact that it was born and has been nurtured in the laboratory undoubtedly has had much to do with this rapid development. Although, like most pure metals, magnesium is relatively weak, when alloyed with other metals its mechanical strength is substantially increased, which has permitted it to be used successfully for engineering purposes. As a result of careful and persistent research, magnesium-base alloys have been developed and improved, and a range of these alloys are available which possess properties that are meeting the demands of the designer and engineer. Aluminium and zinc are the metals most commonly added, with smaller quantities of manganese, but cerium and calcium are also used, and calcium may take the place of zinc in exceptional cases. Further developments in the production of serviceable magnesium-base alloys may be expected in the near future, but those now available have proved their merits, and production of the metal has been forced up at a tremendous rate in an effort to meet the growing demands imposed by war conditions. It is true, of course, that these demands are mainly in connection with aircraft construction, in which its lightness, combined with strength, make it a desirable material for many parts, but there are indications that this metal will play an important part in post-war reconstruction.

In the transport field, magnesium-base alloys will no doubt find their chief engineering outlet, but as Dr. Desch states in his lecture, referred to elsewhere in this issue, they will also find application in many instances in which lightness is an advantage, as in portable machine tools, core-boxes, gravity conveyers, large ventilating fans, and heads for high-speed machine tools. But new applications will undoubtedly develop with time, and many industries will tend to grow as the possibilities of magnesium alloys become increasingly appreciated, particularly in the construction of high-speed machinery, such as some of the textile machines.

The present phenomenal demand for this metal has caused great activity in recent years in its production and known sources of supply are being exploited for its recovery, while methods of recovery have been developed for dealing with certain natural materials which provide a potential source of supply, but from which recovery of the metal presents difficult and complex problems.

Magnesite is the classic source of magnesia. Prior to the war, Austria-Hungary supplied nearly 80% of the world's requirements of magnesia, and Greece supplied most of the remaining 20%. When the Austrian source was shut off at the outbreak of the war, an intensive search was made for magnesite in other countries, and a number of deposits were discovered and developed. Dolomite, the double carbonate of calcium and magnesium, is widely distributed in large deposits throughout the world, and because of its abundance in proximity to power, transportation and markets, has long been regarded as a promising potential source of magnesia and magnesium metal.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

It is noteworthy that until 1941 the sole source of magnesium metal in the United States was the residual brine from salt plants, which constituted a valuable source of magnesium chloride. This source is now greatly augmented by the output from sea-water magnesia plants, as well as other sources mentioned by Dr. Desch. Although enormous volumes of sea-water have to be handled to provide any sizable output, the costs of pumping and settling are not high, and given cheap power and lime, and suitable climatic conditions, it has been demonstrated that magnesia can be recovered from this source at a reasonable cost, especially if the by-products of the process are readily marketable.

The development of sources of supply has also been in progress in Canada, and to eliminate any danger of a disastrous shortage in that country, two plants are in operation—one supplying magnesia, and the other to supply magnesium. The magnesia plant, near Wakefield, Quebec, utilises the recently discovered deposits of brucitic limestone as its raw material and produces pure granular magnesia, suitable both for super-refractories and for the making of magnesium metal by the electrolytic process.

Brucite consists of magnesium hydroxide and has a magnesia content of 69·1% and a water content of 30·9%. It has a hardness between that of gypsum and talc, a specific gravity of 2·38 to 2·4, and crystallises in the rhombohedral division of the hexagonal system. It is translucent to transparent, has a pearly lustre, and most commonly is colourless, white, grey, or pale green, but may be brown, purple, blue or black. Brucite, associated with highly metamorphosed Precambrian limestone, was discovered in the vicinity of Rutherglen in Northern Ontario by Goudge,* during field-work on the limestones of that district in 1937, and later was identified in similar limestone at Bryson and Wakefield, Quebec. The brucite occurs as granules disseminated through the limestone. In none of the deposits does the magnesia content of the rock approach that of magnesite, and in the deposits near Bryson and Wakefield the magnesia content is only that of dolomite. Therefore, without some method of concentrating the brucite, the deposits would have been of little more value as a source of magnesia than is ordinary dolomite, which is abundant in Canada. As a result of investigations in the laboratories is the Canadian Bureau of Mines, a method was developed whereby, from certain of the deposits, pure calcined brucite, or magnesia, in granular form, can be obtained, apparently at a cost that enables it to compete in eastern Canada with imported magnesia.

The magnesia is obtained in granular form by a calcination process and hydrated lime is a by-product. The three principal stages in the process developed are: (1) Calcination; (2) hydration; and (3) separation of brucite and lime.

Calcination is the most important stage in the process and it is essential that temperature is maintained under complete control. Rotary kilns are preferred. If the rock is underburned, it is impossible to obtain a product low in lime, because it will be contaminated with fragments of underburned limestone; on the other hand, if it is over-

burned, the lime will slake very slowly and small unslaked portions will be carried into the final product. In the next stage, which is carried out in a hydrator, usually of the continuous type, the temperature is kept as low as is consistent with satisfactory hydration of the lime. Separation of the brucite from the hydrated lime is effected by an air separator in which the finely divided hydrated lime is removed by controlled air-currents and the granules are discharged to a washing unit for the removal of adhering fine dust.

This brucite magnesia, because of its purity and granular condition, is particularly suitable for the production of magnesium metal by the electrolytic process. It can be converted directly into anhydrous magnesium chloride, without briquetting, thereby dispensing with certain auxiliary materials and effecting a substantial saving in chlorine. It is claimed that this brucite product provides the cheapest source of magnesium so far discovered in Canada

* M. F. Goudge, Trans. Industrial Minerals Division, Bureau of Mines, Ottawa, vol. xlv., 1942, pp. 191-207.

Raw Materials Guide

The Ministry of Supply has issued, through the Stationery Office, what is called the "Raw Materials Guide." This handbook will be of considerable assistance to business men, traders and others interested, who may, in the past, have experienced some difficulty in finding out exactly what the law is relating to particular raw materials. So many statutory rules and orders have been issued that it is extremely difficult for anyone to remember them all. It tells what the raw materials are, what they do, gives particulars of their control and of the statutory rules and orders that have been issued about them.

It is proposed to issue monthly addenda of any changes in controls or in procedure, in order to keep the "Guide" completely up to date. At present it deals with nearly 1,000 different raw materials, and it should prove invaluable to all those who have dealings in raw materials, as well as to those interested in the development of war-time control.

The "Guide" is issued by H.M. Stationery Office, York House, Kingsway, W.C. 2, and is also obtainable through any bookseller, price 1s. net.

Forthcoming Meetings

Sheffield Metallurgical Association

A paper on "The Spectrochemical Analysis of Segregates" will be given by Lt. J. Convey, of Toronto University and the Bragg Laboratory, Sheffield, on March 27, at 2-30 p.m., at 198, West Street, Sheffield. This is a joint meeting with the South Yorkshire Section of the Institute of Chemistry.

On April 10, at the same time and place, Dr. W. J. Rees, F.I.C., will lecture on "Steel Foundry Moulding Materials."

Manchester Metallurgical Society

On March 24, at 6-30 p.m., J. O. Hitchcock, B.Sc., will give a paper on "The Economic Use of Nickel in Non-Ferrous Alloys."

Institute of British Foundrymen.

LANCASHIRE BRANCH.

On April 3, at 3 p.m., W. Brown will give a paper on "Essential Points in Production of Non-Ferrous Castings," following the annual general meeting of this Branch. The meeting will be held at the Engineers' Club, Albert Square, Manchester.

North-East Coast Institution of Engineers and Shipbuilders

On March 26, at 6 p.m., Ezer Griffiths, D.Sc., F.R.S., and M. J. Hickman will give a paper on "Modern Heat Insulating and Deck Materials."

The Influence of Temperature on the Modulus of Elasticity of some plain Carbon and Alloy Steels

ALTHOUGH a very large amount of work has been done on the change of the modulus of elasticity of steels as the temperature is raised from which some suggestions have been obtained that the curves are not smooth, the sensitivity of the methods employed has not been sufficiently great nor have the temperature intervals been sufficiently small to enable one to say with certainty whether the abnormalities found in other mechanical properties exist also in respect of this. Measurements, therefore, have been carried out on a series of steels, both plain carbon and alloyed, using apparatus of the highest sensitivity, determinations of the modulus being made every 2°–3° C., and the results are reported by G. C. Seager and F. C. Thompson.*

Three plain carbon steels and four alloys steels were selected for test, and a specimen of Armco iron strip, cold rolled and annealed, was also tested. Three or more sets of determinations were made on each specimen, the results plotted and the three curves averaged; a mean curve was then plotted. Although all the steels except one were in the soft condition, it was found necessary after preparing the test-piece to hold it for some hours at 200°–250° C. Even then the results obtained on the first—and sometimes also on the second—cooling had to be discarded, the next three or more—which, in general, showed good agreement—being treated as mentioned above. The reproduction of such curves, which had necessarily been plotted on a large scale, is difficult, the actual points obtained being too closely spaced to show.

All the specimens tested show discontinuities the magnitudes of which are very small compared with those obtained by other workers on other elastic properties; nevertheless, they are—with the possible exception of the 180° C. point in one of the plain carbon steels—too great to be accounted for by experimental error, the deviation from the smooth curve being, in some cases, as much as five times as great as could be accounted for in this way. Furthermore, they are not dependent upon the evidence of one particular temperature, the points on each side definitely "leading up" to the discontinuity recorded.

In general, the discontinuities appear to be grouped around three temperature regions, the first about 110°–120° C., the second 160°–170° C., and the third in the region around 220°–230°

* Paper No. 9/1943 of the Alloy Steels Research Committee, Iron and Steel Institute, February, 1943. Advance copy.

Thermo-Electric Power of very pure Iron between 20° and 230° C

THE thermo-electric power of iron has been investigated by more than one worker, but the differences in the results obtained and the purity of the material now available appeared to justify further examination. For this purpose two samples of iron of the highest purity were obtained. One of these was a vacuum-melted electrolytic iron, the second a very pure, vacuum-melted carbonyl iron, both samples being vacuum annealed after drawing.

The thermo-electric power of these irons has been accurately measured in the temperature range from 20° C. to 230° C., and this work, together with the results, are given by F. C. Thompson and N. C. Saha.* The authors report that no abnormalities which clearly exceed the experimental error were noticed. The effects of such factors as the presence of hydrogen and cold work were also investigated, without any discrepancies being observed. The results tend to endorse the view, put forward by Sykes and Jones,[1] that the abnormalities in the mechanical properties of iron and its alloys are not reproduced in its more definitely physical properties.

* Paper No. 8/1943 of the Alloy Steels Research Committee, Iron and Steel Institute, February, 1943. Advance copy.

1 Sykes and Jones, *Journal of the Iron and Steel Institute*, 1939, No. I, p. 435P.

Sir William Chandler Roberts-Austen

K.C.B., D.C.L., D.Sc., A.R.S.M., F.R.S.

CENTENARY LECTURE

By S. W. Smith, C.B.E., D.Sc., A.R.S.M.

Arranged jointly by the Institution of Mechanical Engineers, the Iron and Steel Institute, and the Institute of Metals, to commemorate the birth of Sir William C. Roberts-Austen, this lecture was given by Dr. Smith on March 3, 1943, at the Institution of Mechanical Engineers. Sir William conducted a notable series of researches for the Alloys Research Committee of the Institution of Mechanical Engineers; he was President of the Iron and Steel Institute in 1899–1901, and his name is perpetuated in ferrous metallurgy by the term "austenite." His work in both ferrous and non-ferrous metallurgy stamped him as a truly great metallurgist. He lived for the progress of metallurgy, and he did much to stimulate others by his enthusiasm. Dr. Smith acted as one of Sir William's Private Assistants at the Royal Mint, and therefore is an authority on his life and work.

Drawing by Arnold Radcliffe

Sir William Chandler Roberts-Austen

IN attempting to pay my tribute to the memory of Roberts-Austen on the occasion of the centenary of his birth, I am conscious of the great privilege which has been afforded me by the Institution of Mechanical Engineers in association with the Iron and Steel Institute and the Institute of Metals. To the Transactions of two of these bodies he made many notable contributions, while, had he lived to see the birth of the third, he would, I feel sure, have been numbered among its founders and would have taken an enthusiastic part in furthering its welfare.

Born on March 3rd, 1843, in Kennington, his whole life coincided with a period of intense scientific and metallurgical activity, and, living as he did in the metropolis, and for the greater part of that time at the Royal Mint, amid the historical surroundings of Tower Hill, he had exceptional opportunities of participating in the proceedings of the numerous scientific and technical societies having their headquarters in London, and of being closely associated with those who were concerned with their various activities.

Of his early life I can tell you little. The name by which he is known to us was added, for family reasons, in middle life, when, as William Chandler Roberts, and at the request of a maternal relative, he was granted Royal Licence to add the family name of Austen. But for this circumstance, the graceful tribute paid to him in later years by his close friend, Floris Osmond, who dedicated to him his discovery of the constituent of steel which has perpetuated his name, might have taken another form, and we should not have had the word "Austenite" and its adjectival derivative "Austenitic" as parts of our daily metallurgical vocabulary.

Tradition, however, does point to certain matters of interest in his ancestry, and of these, one which connects him with Isaac Casaubon, who came to this country from Geneva in the seventeenth century at the invitation of James I, is of particular interest, since we are told it was he who revived the study of Aristotle at Oxford, and so, perhaps, prepared the way for the advance of experimental science at the older universities.

His son, Meric Casaubon, settled in Canterbury, and from his union with a member of a Kentish family, Roberts-Austen proudly claimed descent. His maternal grandfather, William Chandler, M.D., was a resident in Canterbury, and it may be mentioned in this connection that Roberts-Austen, after spending the whole of his life in London was buried at Canterbury, at the end of November, 1902.

It is, therefore, now more than 40 years since he was a familiar figure at scientific gatherings and technological proceedings; at the Royal Society, of which he was elected a Fellow as far back as 1875, at the Royal Institution, the Royal Society of Arts, the Physical Society (of which he was one of the founders), the Chemical Society, the Institution of Civil Engineers, and, of course, at the meetings of the two senior bodies represented here to-night.

Early Influences

It is of interest, I think, that we should take a glance at the background of his earlier professional career and consider for a moment the extent to which his bent for

scientific investigation was influenced by those with whom he became associated and under whose inspiring influence his aspirations were, no doubt, stimulated. Of these I would mention three to whom he paid generous tributes in later years.

First of all, Dr. John Percy, his Professor at the Royal School of Mines—then situated at Jermyn Street and occupying a portion of the building which accommodated the Geological Survey and the Museum of Practical Geology. Entering in 1861, at the age of 18, and, originally with the intention of pursuing mining as a career, it was undoubtedly due to Percy that his interests were deflected to metallurgy.

At that time Percy had already occupied the Chair of Metallurgy for 10 years, and had already made much progress in his stupendous and self-imposed task of compiling his classical treatises on the history and practice of metallurgy in all its branches. Although so many of his students took prominent parts in the subsequent developments of non-ferrous mining and metallurgy in all parts of the world—particularly of the so-called "precious metals"—it is interesting to remember that the metallurgy of iron and steel occupied a good deal of Percy's time and attention, leading in later years to the Presidency of the Iron and Steel Institute. Roberts-Austen, in his tribute to Percy, which appeared in the Proceedings of the Royal Society (1889), said: "Of all his work, that relating to iron and steel is perhaps the most important." It is tempting to dwell at greater length on the inspiration which Roberts-Austen derived from Percy, in whose footsteps he followed, first as his successor at the Royal School of Mines, and later as President of the Iron and Steel Institute.

Having completed the course at the School of Mines, Roberts-Austen, no doubt on the recommendation of Percy, went to the Royal Mint in 1865 as personal assistant to Thomas Graham, one of the most distinguished chemists of his day whose interests were largely in the field of physical chemistry, and were devoted, as we know, to the elucidation of the nature of molecular movement in gases, liquids and metals.

As Master of the Mint at that time, Graham was the successor of many eminent men distinguished for their scientific work, of whom, of course, Isaac Newton stands supreme (1696-1727). This post, in fact, was perhaps one of the first, and moreover one of the few, to which the Government gave direct recognition to scientific distinction. For four years—that is, until Graham's death in 1869—Roberts-Austen continued to assist him in his private laboratory at the Mint, but in no direct way associated with the operations of coinage. During this time, Graham was pursuing his researches on the diffusion of gases in metals and, in particular, the classical work on the occlusion of hydrogen by palladium, in which Roberts-Austen felt justifiable pride in having participated. In later years he had many opportunities of paying tribute to the memory of Graham and his own work shows how much he owed to him. A striking aptitude which is traceable to Graham's influence is the remarkable facility with which he readily adapted simple means to important ends.

At the death of Graham the office and title of "Master of the Mint" was in future to be held, *ex officio*, by the Chancellor of the Exchequer, while the actual administration of the Department was entrusted to a "Deputy Master and Comptroller." Roberts-Austen was retained in an official capacity as "Chemist to the Mint," and was entrusted with the responsibility, as an Assayer, and still occupying Graham's laboratory, of ascertaining and certifying the legal composition of all standardised alloys and finished coins—a duty which since 1851 had been carried out by non-resident or "outside" assayers, but which in preceding years had for centuries been the responsibility of the King's (or Queen's) Assay Master. These administrative changes, which were accompanied by a reorganisation of all the departments of the Mint, and incidentally established Roberts-Austen in a position of official responsibility, also brought him into intimate relations with a distinguished Civil Servant—the Hon. Sir Charles W. Fremantle, K.C.B.—who became the first Deputy Master and Comptroller under the new arrangement. The inauguration of a series of annual reports on the work of the Mint for the use of the House of Commons coincided with his appointment in 1870. The masterly style and command of English which characterise Fremantle's contributions to these reports may not have been entirely unconnected with the fact that he had formerly acted as Disraeli's private secretary. It is certain, I think, that Roberts-Austen's meticulous care in presenting the results of his work and in addressing various learned Societies owed something, at least, to his close association with Fremantle over a period of some 25 years. In dedicating to him the first edition of his well-known treatise—"An Introduction to the Study of Metallurgy"—in 1890, he said: "For more than 20 years there have been few things, except this dedication, about which I have not consulted you. The book embodies the results of many investigations conducted in the Mint during that period, and the encouragement you have always given to research and your interest in its progress, have been most helpful."

A further reorganisation of the work of the Assay Department occurred in 1882, on the retirement of Mr. E. L. J. Ridsdale, the officer responsible for the valuation of all gold and silver bullion imported into the Mint, an office formerly styled the "Master's Assay Master," and one which had provided for the protection of the Master against the contractors or "Moneyers" who had performed the operations of coining until 1851. As the Master of the Mint could no longer be brought into conflict with outside interests, the Treasury decided to combine the two Assay offices and Roberts-Austen was then given full charge of the valuation of bullion at all stages, with the title of "Chemist and Assayer of the Mint." This office he continued to hold, never releasing himself from a share in the daily responsibilities of routine work, until, on the death of the then Deputy Master (Sir Horace Seymour) early in 1902, he was called upon to add the duties of that office to those of his own.

It is quite impossible to deal with Roberts-Austen's work at the Mint as a matter apart from his many activities in all directions. It is quite certain that he formed a great attachment to the Mint, and the many years during which he lived and worked there were undoubtedly happy years.

His Work at the Mint

Shortly after his appointment, in 1870, as Chemist to the Mint, he had an opportunity of gaining what, at that time, was a unique experience—that of visiting, in company with Sir Charles Fremantle and the Superintendent of the Operative Department, Mr. J. M. Napier, thirteen of the principal European Mints. This journey took him to Madrid, Milan, Florence, Rome, Constantinople, Vienna, St. Petersburg, Stockholm, Copenhagen, Berlin, Utrecht, Brussels and Paris. Thus, at the very outset of his official career he became acquainted with phases of minting under widely varying conditions. It was during these visits that he was able to initiate many of those close associations with men of science on the Continent which in later years developed into valuable relationships, having in many cases an international significance. One immediate outcome, the result of conferring with Stas—at that time the head of the Brussels Mint—was the introduction to this country of the volumetric method of assaying silver to replace the old method by cupellation. This newer method had been devised originally by Gay Lussac and adopted at the Paris Mint in 1830, but it was without doubt due to the confidence inspired by Stas, who himself had done

much to facilitate the manipulations required for dealing quickly with large numbers of assays, that Roberts-Austen was able to replace a method, hallowed by long tradition and executed with skill, by one more in keeping with the progress of analytical chemistry.

It was at this time, too, that he was brought to realise, from a practical standpoint, a metallurgical truth which continued to occupy his attention in one way or another throughout his whole career. It arose from a serious difficulty which had been encountered as between the Bank of England, as importers of gold, and the Mint in converting that gold into coin. Considerable quantities of this gold had proved, on alloying with copper, to be brittle, and quite unsuitable for coinage. This was not a new problem, as "brittle gold" had long been one of the recurring difficulties of minting, and one of which it was always difficult to apportion the blame, as both the fine gold itself and the best grades of copper then obtainable, with which it was alloyed, were themselves malleable. A lengthy correspondence was abruptly terminated in a practical way by Roberts-Austen, who suggested a means of eliminating the traces of the offending elements, and so toughening the gold by the adoption of the process recently devised by his colleague, Mr. F. B. Miller, of the Sydney Mint, for refining gold by the passage of chlorine gas through the molten metal—a process now in general use throughout the Empire.

I have mentioned this incident as an early example of his life-long concern with the profound influence which small quantities or "traces" of one element may have on another—a matter to which he recurred again and again with insistence and brought home with striking examples from metallurgical practice, particularly, of course, in relation to iron and steel.

The earlier years of his official career continued to be devoted almost exclusively to matters directly related to the operations of Minting, and the thoroughness with which he explored the historical records of the art is shown by the admirable series of Cantor Lectures which he delivered before the Royal Society of Arts, in 1884, on "Alloys Used for Coinage." These lectures embodied the main facts in regard to the history of monetary alloys and the developments of various appliances from the simpler types which had either been devised or employed by the great artists of the sixteenth and seventeenth centuries, Leonardo da Vinci, Cellini, Briot, Simon and many others. A few years later (1887) he contributed an article of considerable interest to *Murray's Magazine*, which gives some indication of the antiquity of the office to which he had succeeded, although with another designation. Under the title of "The Queen's Assay Master," he traced the history of that office from the time of Henry III, and although, as he said, "in the case of Assay Masters 'oblivion blindly scattereth her poppy' still their influence has not been without record in history." With this article he also reproduced illustrations of some of the remaining portions of the Ancient Trial Plates which had served as the Standards against which the coinages had been checked, in continuous sequence, from the time of Edward IV (1477). These plates—some 30 in number—symbolise, he said, centuries of responsibilities, and he expressed justifiable pride in the privilege of continuing the succession.

One is tempted to dwell longer on the variety of interests which Roberts-Austen found to attract his attention in those earlier years—such, for instance, as the repetition of some of Spring's work of 1878 and 1880 on the compression of metallic powders, which we now call "powder metallurgy"—but one must keep steadily in mind the lines along which he developed his main contributions to metallurgical progress. An important milestone is, undoubtedly, a remarkable paper which he contributed to the Proceedings of the Royal Society as early as 1875, "On the Liquation, Fusibility and Density of Certain Alloys of Silver and Copper." This work arose directly from the duty which had been entrusted to him, two years previously, by the Warden of the Standards, of preparing new Trial Plates to constitute the legal standards of reference in checking the gold and silver coinages at the Annual Trials of the Pyx by a Jury of the Goldsmiths' Company, and also for use at the Assay Offices of the United Kingdom, in substitution for those then in use, which were known to diverge slightly in uniformity of composition from the precise standards prescribed by law, a deviation attributable to a segregation of the constituents during solidification.

In seeking to explain this behaviour, which had long been known in relation to the alloys of silver with copper, he set himself the task of determining, in the first place, the temperatures at which the alloys of these metals solidify when the composition ranges from pure silver to pure copper. With modern pyrometric equipment this would appear to be a comparatively simple matter, but at that time the only course open to him was to adopt a modification of a procedure employed by Pouillet in determining the specific heat of platinum at high temperatures by the use of calorimetric methods. A wrought-iron cylinder of known weight and specific heat was immersed in the molten alloy and then withdrawn when the metal showed signs of solidifying and quickly transferred to a calorimeter of the type then in use for determining specific heats by the method of mixtures. To determine the specific heat of the iron itself, at some fixed point near the maximum temperature likely to be reached, he was limited in his choice of an ascertained temperature for this purpose to calibration. He relied on a figure for the melting-point of pure silver, which had been given by Edouard Becquerel, but this, in turn, depended on the vapour of boiling zinc, which Deville had fixed at 1,040° C., but this figure for silver was some 79° C. too high. Even greater uncertainty existed as to the melting-point of copper, which he found great difficulty in determining by the method he was using. It was not, however, essential to his inquiry, but it is interesting to note that the only figure then available had been given by Van Riemsdijk as 1,330° C.—actually 245° C. above the true value. The fifty or so observations of freezing points, which were recorded in this paper, were plotted, graphically, and these curves constitute the first recorded "Freezing-Point-Curve" of a series of alloys which solidify beyond the range of the glass thermometer, and which therefore demand pyrometric methods. Referring to this work some 23 years later, when he had repeated his examination of the same alloys by the use of thermocouples and his recording pyrometer, and when the still more refined determinations by Heycock and Neville were available, he said: "The method adopted was very imperfect, but the curve plotted from the results of the experiments truly revealed the nature of the alloys under examination, and, viewed in the light of modern knowledge, the curve shows to which group of solutions the copper-silver series belongs." He showed that when corrections were applied for the freezing points of silver and copper, which had since been accurately determined, the degree of concordance with later work was remarkable. This early attempt to make measurements of the temperatures at which alloys of high melting point solidify led his friend and colleague, Professor Guthrie, to embark on a memorable research, published under the title of "Eutexia," by which he connected the cryohydrates of saline solutions with the eutectics in alloys, and it is to him that we owe the word "eutectic."

Thus, although Roberts-Austen's original intention in undertaking this work was to find an explanation of the segregation which occurs when alloys of the precious metals solidify from the molten state (a behaviour which, following the train of thought which he had inherited from Graham,

he spoke of as " molecular mobility "), the actual outcome of this work was the direction it gave to a search for more accurate methods of measuring and recording high temperatures, and to the means which these would afiord of studying the constitution of other series of alloys. The question of the segregation of the constituents of the Trial Plates of Standard Gold and Standard Silver was left in abeyance, although the main facts of these occurrences were studied and recorded in the same paper. The immediate practical requirements of entirely trustworthy standards of reference were met by his suggestion—which was officially adopted—that the Standard Plates required by law should be supplemented by Plates of Fine Gold and Fine Silver.

From now onwards for many years he sought to make available a means of recording autographically those changes in the rates of heating and cooling of metals and alloys which accompany changes of phase below and above their melting-points. For this purpose he followed the lines which had been initiated by Henri Le Chatel'ier, who had shown the possibilities of making use of thermo-couples of platinum and platinum-rhodium for this purpose.

The recording pyrometer continued to be his chief implement of research until he adopted the methods of photomicrography in 1895, which became complementary to it. He made effective use of these two lines of approach in revealing the molecular changes taking place in metals and alloys and in demonstrating the reality of those changes by photographic means. Demonstration was, in fact, one of his most useful attributes at a time when there were few opportunities for those immersed in engineering and productive work of becoming even acquainted with the trend which physical metallurgy was beginning to take.

Another feature of his early work, which also arose directly from a difficulty encountered in Mint practice, was the attention he gave to steel suitable for the manufacture of coinage dies. This investigation was made in 1880 and marks the commencement of his interest in the properties and constitution of steel which continued to the end of his career. This early inquiry into the conditions which affect the hardening of steel led directly to the beginning of his long association with the Institution of Mechanical Engineers, which in later years yielded such important results. He was requested by the Institution to undertake certain experiments with a view to ascertaining whether occluded gases play any part in the hardening and tempering of steel. The results of these experiments were published in the Proceedings of 1881.

The first of his many contributions to the Proceedings of the Iron and Steel Institute, " On the Electro-deposition of Iron " in 1887, was also the outcome of his official work. Difficulties had arisen in the preparation of metallic reproductions of the plaster models of designs for the new coinage to be introduced during the year of Queen Victoria's Jubilee. Hitherto, the models employed in the reducing machines had been obtained either by special forms of iron castings or by electrotypes of copper. The latter proved too soft to withstand the action of the travelling pointer in its passage over the design during the transference of its movements to the steel in which the matrix is cut. Roberts-Austen succeeded in producing sufficiently hard reproductions of the original designs for this purpose by the electro-deposition of iron. He gave full acknowledgment of the help he had received in this art many years previously from M. de Jacobi, of St. Petersburg, one of the earliest workers in the field of electro-metallurgy. He made a further examination of the properties of electro-deposited iron, the results of which are recorded in the paper to which reference has been made. This incident is of interest because in later years, with a refinement of pyrometric records, he used similar material to determine the points of transformation which occur during the cooling of pure iron from high temperatures.

Another line of investigation arose from his official work. In the course of assaying gold bullion, a daily occurrence is the " recalescence " or " flashing " of the cupelled buttons of the " parting " alloy of gold and silver. This phenomenon led him in later years to make an extended examination of the " undercooling " or " surfusion " of alloys. The results were communicated to the Royal Society in 1898.

These five examples of his early work at the Mint are sufficient, I think, to show how he was led, from what one might regard as parochial difficulties, to extend his inquiries to wider fields and to matters of fundamental scientific and metallurgical importance.

From the presence of traces of impurities in standard gold he passed, in time, to the consideration of the effects of traces of impurities in pure metals and of elements deliberately added both to ferrous and to non-ferrous metals. From the difficulty in securing uniformity in the official standards of reference of the gold and silver coinages, he passed to the determination of the molecular changes occurring during the passage of molten alloys to room temperatures. The need for the provision of better steel for the manufacture of coinage dies led to a closer study of the iron-carbon alloys, while the preparation of electro-deposited reproductions of plaster models furnished him with the means of studying the molecular transformations in pure iron.

Before passing to a closer consideration of this work, it will be well, I think, to preserve some chronological sequence by a brief reference to his work as a teacher.

The Royal School of Mines

Seventeen years elapsed from the time Roberts-Austen left the School of Mines in 1865 until he again became directly associated with it in 1882. During this period his reputation had been growing steadily, both as a worker in the laboratory and as a lecturer in public. A decision had been reached by the Council for Education to transfer the instruction in Metallurgy from Jermyn Street to South Kensington. Certain other branches of the School had already been detached and established there, but Percy made a strong appeal for the retention of his department in continued association with those of Mining and Mineralogy, and even made the generous offer to build a laboratory there at his own expense. The decision, however, was not revoked, and Percy regretfully decided to resign his position. It was under these somewhat clouded circumstances that Roberts-Austen was invited by the Lord President of the Council to occupy the Chair of Metallurgy at South Kensington. This appointment was accepted with the full consent and approval of the Lords Commissioners of the Treasury, to whom representations had been made by Sir Charles Fremantle as to the advantages which would accrue to his Department by this closer association with advances in metallurgical practice.

In his inaugural lecture as Professor of Metallurgy, Roberts-Austen gave a scholarly and historical review of the " Relations of Metallurgy to Chemical Science." This was followed in 1885 by an address, at the opening of the new School of Metallurgy at the Birmingham and Midland Institute, on the " Development of Technical Instruction in Metallurgy." In 1891, as President of the Chemical Section of the British Association, he chose as the subject of his address, " The Relation between Theory and Practice in Metallurgy." His outstanding contribution to the teaching of his subject, however, was the compilation of the volume to which reference has already been made, " An Introduction to the Study of Metallurgy "—first published in 1891 and revised in later editions, each growing in bulk and usefulness, the fifth edition being published just before his death. Reference has already been made to his dedication of this volume to Sir Charles Fremantle. Two

quotations which appeared on an adjoining page may be taken, I think, as the chosen expressions of the aim he had in view as a teacher—

> "I rather open than discover things."
> —*Montaigne's Essays* (1580).
>
> "To know
> Rather consists in opening out a way
> Whence the imprisoned splendour may escape,
> Than in effecting entry for a light
> Supposed to be without."
> —*Browning's "Paracelsus"* (1835).

A contemporary review of this volume summarised its main features by saying: "There has been a distinct want of a systematic exposition of the general principles of metallurgy and of clear statements as to the physical characters of metals and alloys . . . The author has deliberately subordinated details of smelting operations in order that he might deal at length with the physical properties of metals and the constitution and characters of alloys, modified as these properties often are by thermal treatment and the presence of small quantities of foreign elements. Such questions are treated with much wealth of research and abundant reference to authority. The book will hardly be popular with the class of students who merely attempt to cram."

During the 22 years of his professorship, Roberts-Austen was associated with many eminent colleagues. Huxley became the Dean in 1881 and continued to direct the work of the Royal School of Mines and the Royal College of Science until his death in 1895. Other familiar names are those of Judd, Warrington-Smyth, Le Neve Foster, Frankland, Edward Thorpe, Guthrie, Rücker, Goodeve, and Perry. Norman Lockyer, who had been associated with Roberts-Austen in an investigation of the quantitative analysis of alloys by the spectroscope as early as 1873, was appointed to the Chair of Astronomical Physics contemporaneously with Roberts-Austen's appointment in 1881.

In a valedictory letter to the students of metallurgy, two weeks before his death, he commended to them, as his successor, his old friend and fellow associate of the School of Mines, William Gowland, and he assured them of his life-long interest in "our School" and of his warmest solicitude for the welfare of the students

The Reports to the Alloys Research Committee Institution of Mechanical Engineers

Roberts-Austen had long wished to ascertain whether the influence of small quantities of impurities on the physical and mechanical properties of metals is governed by any law. The general interest which had been aroused in the 'eighties by the enunciation of periodicity by Newlands and by Mendeleeff, in relation to the chemical properties of the elements, had, no doubt, led him to seek some such generalisation in regard to alloys.

In a paper to the Royal Society in 1888, "On Certain Mechanical Properties of Metals considered in Relation to the Periodic Law," he reviewed some of the practical implications of the presence of small amounts of other elements in metals of relative purity. As regards copper, he quoted an observation recently made by Mr. (afterwards Sir William) Preece, that "a submarine cable will now (1888) carry twice the number of messages that a similar cable of copper would in 1858 when less importance was attached to the presence of foreign matter in the copper." The experimental work recorded in this paper was an attempt to relate the atomic volumes of 17 elements to their effect on the mechanical properties of pure gold to which small amounts of the order of 0·2% had been separately added. He claimed that "not a single metal or metalloid which occupies a position at the base of either of the loops of Lothar Meyer's curve diminishes the tenacity of gold. On the other hand, the fact is clearly brought out that metals which do render the gold fragile all occupy high positions in Meyer's curve." His speculations at this time are of particular interest in relation to modern work on the constitution of alloys.

It was, however, as the direct outcome of this work that we find recorded in the Proceedings of the Institution of Mechanical Engineers (Annual Report, January 29, 1890, p. 6) that, on the recommendation of Dr. Anderson, the Council had decided upon starting a Research Committee with the object of furthering the investigations which Roberts-Austen had already made, but with special regard to the physical and mechanical properties of iron, copper and lead. Reference was also made to a previous suggestion by Mr. John A. F. Aspinal as to the desirability of inquiring into the serious deterioration experienced during recent years in the durability of copper fireboxes and brass tubes of locomotive boilers. The hope was expressed that one result of the investigations might be to elucidate the causes of these failures and that "the laws regulating the effects of small admixtures of other elements with iron will also be arrived at."

Thus we see that the original intention of those responsible for setting up this Committee was that the inquiries should embrace both non-ferrous and ferrous metallurgy, terms, however, not then in general use. Under the chairmanship of the then Director-General of Ordnance Factories at Woolwich, Dr. (afterwards Sir William) Anderson, it was only natural and, moreover, fortunate, that the scope of the investigations should be a wide one.

During the 10 years which followed five reports were presented to the Institution. It was, perhaps, through the medium of these reports and the vigorous discussions which they provoked, that Roberts-Austen's enthusiasm had the greatest practical effect, leading to widespread and permanent results. These reports were mainly exploratory, and at times, seemingly, discursive, but coming as they did, at a time when men occupying the highest positions in the engineering world were frankly sceptical as to the possibility of the pyrometer or the microscope serving any real purpose as an indication of the suitability of material for engineering work, they did much to arouse interest and to carry conviction to those dealing with metallurgical problems differing very widely in their character. One of the features, in fact, of Roberts-Austen's usefulness at this time was the close touch he kept with workers in many fields, from whom came inquiries and information which might never have reached the notice of a less accessible person. Scarcely a day passed without a visit to the Mint by someone, eminent himself, perhaps, in some branch of technology, but seeking instruction or enlightenment on some aspect of the work in hand. To these visitors every facility was freely offered. The day was often taken up by such visits, the researches being continued at night. At a time when such rapid advances were being made in all directions, the work with which the Committee had entrusted him did much to establish and to uphold the best traditions of metallurgical research in this country.

The First Report

At the outset he drew attention to Osmond's recent work on the allotropy of iron and his experimental study of the action of impurities on iron. His admiration of Osmond's work was repeatedly manifested during the years which followed, and a close friendship and intimate correspondence continued between these two men until the end. In fact, it is just, I think, to say that in many ways Roberts-Austen was Osmond's disciple, preaching the gospel of allotropy in this country and introducing to his countrymen, in the later reports, the exquisite metallographic technique which Osmond had developed, not forgetting, of course, our indebtedness to Dr. Sorby and to others. A considerable part of the first report was directed to the question of temperature measurement as a fundamental necessity in carrying out the proposed investigations. A careful description was given of means taken to adapt the Le Chatelier

pyrometer to give autographic records. The applications of this apparatus to the examination of alloys and to the cooling of steel were shown by many examples. For a time the previous work on the addition of small amounts of other elements to pure gold was continued in order to determine the "atomic fall" of the freezing point of gold by lead, bismuth, platinum, silicon, manganese, aluminium and silver respectively. But attention was soon diverted to matters of practical importance, and experiments were described and curves given showing the different times and different temperatures at which transformations take place at the centre and at the circumference, respectively, of a steel ingot. Osmond had already pointed out that the rate of cooling has a measurable effect upon the temperature at which molecular changes occur.

The report concludes: "In all these experiments it was found that the flow of heat from the centre of an ingot was not sufficiently rapid to prevent there being considerable variations in temperature within the mass. There can be but little question that such experiments well deserve careful attention, and in the hands of competent observers should be fruitful of results."

The Second Report

Reference was again made to the possibility of the periodic law having some relation to the effect of added impurities, but it was now realised that an attempt to prove the nature of this relation merely by mechanical tests would certainly lead to anomalies and more or less grave irregularities. His own work on the atomic lowering of the freezing point and also that of Heycock and Neville (whose masterly work was then under weigh at Cambridge) had raised the question as to whether the added element, when in larger proportions, does or does not remain free in the mass of the solvent. He recognised that this question was a vital one. A diversion was made to consider what was then regarded as "molecular porosity" in view of some remarkable experiments which had been made by Warburg and Tegetmeier on the passage of elements through vitreous bodies. These experiments were regarded as being of sufficient interest to warrant repetition and extension. In commenting on this work, and of course with no knowledge of the future disclosures by X-rays, he said: "In all probability, therefore, the introduction of free molecules of an added element must create a disturbance, the nature and magnitude of which will bear some relation to the volume of the disturbing atom."

Attention was again given to matters having a more practical bearing, and exhaustive experiments were described of the effects of impurities on copper. In the case of bismuth, the low subordinate freezing point was discovered and recognised as being the cause of brittleness, a direct outcome of the Committee's work and a striking example of the possibilities of usefulness ahead. A valuable contribution to this report was made by Mr. William Dean, of the Great Western Railway, on copper plates for the fireboxes of locomotives.

The effect of pressure on metals was next considered, and particulars were given of experiments to lower the recalescence point of steel by compression. An interesting observation was made in this connection with a triple alloy of bismuth, lead and tin (known as Newton's metal) which was found to show a remarkable rise in temperature long after the metallic mass had solidified. He showed that certain analogies exist between the behaviour of this alloy when suddenly cooled and the changes which take place in steel during hardening. One wonders if he were then on the verge of discovering what has since come to be known as "age-hardening."

Chromium steel was examined, and he drew attention to the importance of studying the relation of this metal to carbon and iron. How little could he have anticipated the part which this metal was to play in those steels in which his own name was to be perpetuated by his friend Osmond.

The Third Report, 1895

Much of the work which followed was in the nature of exploratory research in various directions. Curves were shown of the cooling of electro-iron, of standard gold containing bismuth, of aluminium-copper alloys, and of iron-aluminium alloys. Observations were made of the spontaneous disintegration of the latter. The welding of iron was then examined in conjunction with Sir Thomas Wrightson. Experiments in welding were made by electrical means and pyrometric measurements were made during the application of pressure to the plastic iron with the object of ascertaining whether the operation is attended by a fall of temperature as in the regelation of ice. The work of Dewar and Fleming on the behaviour of metals at very low temperatures had been recently published, and the bearing which their work might have on the questions under consideration by the Committee was discussed.

With this report two important appendices were included by two of his own students. Alfred Stansfield, who was then assisting Roberts-Austen, contributed the results of his work on "The Pyrometric Examination of the Alloys of Copper and Tin," which represents the first attempt to give an explanation of the copper-tin series of alloys as a whole, and marks the beginning of many subsequent investigations by other workers in correlating the physical and mechanical properties of these alloys with their equilibrium diagram. Mr. Allan Gibb contributed an exhaustive account of the stages by which impurities were then being eliminated from copper during the process of making "Best Selected" brands.

The Fourth Report, 1897

The opening paragraphs of this report contain much that is of historic interest, and they constitute, moreover, a concise statement of the position which the Committee's work had reached. A few lines may, perhaps, be quoted: "The value of the experiments on the nature and properties of alloys which were originated by the Institution of Mechanical Engineers in 1890, has received wide and appreciative recognition in this country and abroad. It may be fairly claimed that they have stimulated similar work in France, for the constitution of our Alloys Research Committee and the course they have adopted has confessedly been closely followed by the "Commission des Alliages" of the "Société d'Encouragement pour l'Industrie Nationale." He added: "It should not be forgotten, moreover, that excellent investigations on alloys have also recently been made at Cambridge by Heycock and Neville, whose work has been carried on side by side with that of our Committee."

He concluded these opening paragraphs by saying: "As regards the immediate future, I am of opinion that the nature of what may be called "solid solutions" of metals must be more carefully studied than has hitherto been the case. . . . It will be necessary to place on a firmer basis our knowledge of the mechanical constitution of metals and alloys, as revealed by the pyrometer and the microscope before attempting to explain how "structure" is built up of the ultimate atoms or molecules of the metals." This, of course, with no inkling of the contributions to the questions of structure which the physicists were to make within a very few years.

Following the work on the alloys of copper and tin given in the third report, came a similar investigation of those of copper and zinc, which had been in progress for nearly two years. While nearing completion, Charpy presented the first report of the Commission des Alliages, which was devoted entirely to a study of these alloys. His conclusions as to the mechanical properties of the brasses under varying conditions of working and heat-treatment were discussed in relation of the freezing point curves which were published for the first time in this report of the Alloys Research Committee.

As an indication, however, of the difficulties presented at that time in forming views as to the precise manner in which small quantities of an element may influence the properties of another, Roberts-Austen raised some pertinent questions. He said: "It might at first appear that nothing could be simpler than to test the mechanical properties of copper to which, say, one-tenth of 1% of lead has been added. But the question at once arises, what has happened to the metallic lead? Has it remained free? Has it united with a certain amount of the copper to form a fusible eutectic alloy? Has it abstracted oxygen from the copper, becoming itself oxidised? Has it united with the copper to form a 'solid solution'? Or, lastly, does it form a true chemical compound with the copper? It is only reasonable to ascertain what has probably happened to an added element before making elaborate tests on a metal of which chemical analysis is incompetent to disclose the condition in which it exists in the metal."

The diffusion of metals which had long occupied his attention and which had recently formed the subject of his Bakerian Lecture to the Royal Society, was discussed in relation to alloys generally. With regard to the diffusion of solid metals in each other, it was pointed out that the experiments had shown that it is possible actually to observe and measure the migration of the constituent atoms in a metal or alloy at the ordinary temperatures, pointing to unexpected possibilities of structural changes in metals used in engineering construction generally. His determination of the coefficient of diffusion of gold in solid lead was the first of its kind, and has proved to have been very nearly correct. His interest in this aspect of molecular mobility is surely traceable to his early association with Graham. In the course of the discussion of this report an important announcement was made by Roberts-Austen with regard to work which was in progress to bring out the close analogy between the alloys of the iron-carbon series and ordinary saline solutions. The question was further developed by Dr. Stansfield, and curves were presented which, with subsequent elaboration, marked the foundation of the equilibrium diagram of these alloys. The substance of this report differed from previous work by dealing with metals and alloys after they had become solid. The problem was being approached on the lines of the theory of solutions and of Osmond's views, dating from 1888, that the allotropy of iron itself is essential to the theory of the hardening of steel.

The Fifth Report, 1899

The ultimate transference of the work of the Alloys Research Committee to the National Physical Laboratory was foreshadowed in the opening paragraphs of this report. The Committee had exerted a noteworthy influence in connection with the preliminary inquiry which had led to the recommendation by a Treasury Committee, of which Roberts-Austen was a member, that a National Physical Laboratory should be established having its control vested in the Royal Society.

The results of the experimental work published in this report, which are of outstanding importance, are those which sought to support the view that the iron-carbon alloys should be considered as solutions and brought into line with ordinary saline solutions. The curves already given in the previous report had clearly indicated the possibility of such an explanation, but the provision of a new and highly sensitive method of recording temperature changes, which was described at length, made it possible to resume this investigation. Although such cooling curves had been obtained previously by Osmond so long before as 1888, and more recently by Henri Le Chatelier, those given by Roberts-Austen in the fourth report constituted the first attempt to embody in curves a comprehensive series of results.

The remarkable capabilities of the delicate methods of pyrometric record now available and for which he was largely indebted to the skill of Stansfield as a physicist, were demonstrated by reference to the special case of the cooling of electro-iron from a white heat. The complete curve shown afforded striking evidence of the soundness of Osmond's views as to the allotropy of iron. In addition to verifying those molecular changes which were already well known, the investigations threw new light on the relation of iron and hydrogen. Curves were then presented to the Institution which represented the constitution of carburised iron as far as it was then known. It was from these curves that Roozeboom drew his conclusions as to the applicability of the Phase Law of Gibbs.

The latter part of the report was devoted almost entirely to a description of the methods of microscopic examination and to a discussion of its possibilities. It was, perhaps, this aspect of the work which attracted the greatest attention at a time when information regarding the technique of metallography was scanty and not readily accessible. It became, in a sense, a textbook for those who were anxious to pursue similar inquiries in relation to their own problems.

The period immediately preceding and following the issue of this report may be regarded as the climax of Roberts-Austen's activities. Inquiries and suggestions poured in from all quarters, and there were daily consultations. The apparatus which had been improvised became the model from which more elaborate arrangements were installed in many centres of industry throughout the country, but more directly at the Royal Arsenal, Woolwich, at Elswick and at Cambridge.

In the introductory paragraphs to the sixth report, drafted shortly before his death, he wrote: "In the future it will be realised how much the Institution of Mechanical Engineers has done to confirm, strengthen and diffuse the knowledge we possess on the important question of hardening steel."

Quite apart from the actual value of the experimental work recorded in these reports, much of which was that of groping for general principles, it was—I think—the stimulating effect of the discussions which were provoked which did so much to bring together men with fresh ideas and which directly led to the foundation of a school of physical metallurgists who played such important parts in the progress of this work in the years which followed. In addition to those who were his personal assistants during these years and to whose work he made generous acknowledgment—to Henry C. Jenkins (first and second reports), to Alfred Stansfield (third, fourth and fifth reports), to William H. Merrett (fourth and fifth and, after his death, the sixth report), and to A. J. Brett (fifth report), one may recall the names of others who at one time or other went to the Mint for varying periods and worked in the vaulted chambers—collectively known as "The Cellars." Of these, Carpenter, Rosenhain, Hudson, Bengough, Law, Bannister, Reinders, and Campbell, are names which, as we know, are identified with the period which saw the birth of the Institute of Metals.

I may, perhaps, recall that the first President of that Institute, Sir William White, was, at the termination of Roberts-Austen's work, the Chairman of the Alloys Research Committee and the President of the Institution of Mechanical Engineers, and it was in no small measure due to his unfailing support and to his foresight that the work was continued at the National Physical Laboratory and that the Institute of Metals became the medium by which the results of so many later researches have been made available to the workers of all nations.

I am particularly grateful to Mr. Shaw Scott, the Secretary of the Institute of Metals since its foundation, for the part he has taken in initiating this commemoration.

Departmental Committees

Running concurrently with the later phases of the Alloys Research reports were the increasing demands made upon his time and energy by official committees of inquiry set

up by various Government Departments. Of these, the first in which his authority in regard to matters relating to iron and steel received recognition was that of a Committee, appointed in 1896 by the Board of Trade to inquire into the "Loss of Strength of Steel Rails Through Use on Railways." The investigations were prolonged, the final report appearing four years later (1900). Roberts-Austen was entrusted with the photomicrographic examination of a large number of selected rails which had been tested by the Committee and apportioned among the members for further examination. He expressed his great indebtedness to Mr. (afterwards Assistant Professor) W. H. Merrett, his devoted assistant, who "has most patiently and ably aided me throughout this long investigation." A summary of this work was afterwards presented to the Institution of Civil Engineers.

From time to time the Ordnance Committee of the War Department had submitted to him samples of steel used in the manufacture of guns and armour-plate, and he continued, until his death, to be in active co-operation with the War Office and with the Admiralty in elucidating problems in the manufacture of ordnance. In 1898 he had contributed an important paper to the proceedings of the Iron and Steel Institute at the Stockholm Meeting on "The Action of the Projectile and of the Explosives on the Tubes of Steel Guns." He had previously shown to the British Association (Toronto, 1897) some striking resemblances between the action of a projectile in striking an armour-plate and the "splash" produced by a sphere falling into water.

In 1900 he was appointed a member of a Special Committee set up, jointly, by the Admiralty and the War Office, to consider certain questions which had arisen in relation to explosives and ordnance. This Committee was composed of distinguished men, who were quite independent of either of the two Services. Lord Rayleigh was chairman, and with him were Sir Andrew Noble, Sir William Crookes, the Rt. Hon. R. B. (afterwards Lord) Haldane, and Roberts-Austen. His own contributions to the work of this Committee followed the lines of his earlier work, to which reference has been made. The resources of pyrometry, calorimetry, and metallographic examination were enlisted and experiments were conducted both at the Mint and at the Research Department at Woolwich on lines suggested by him. It is believed that he was one of the first to appreciate the advantages of the addition of small quantities of vanadium to nickel-steel for the purposes under consideration. His death, however, prevented the completion of this work, which, it was said, promised to furnish valuable information.

His Addresses

While his contributions to the Transactions and Proceedings of various scientific and technical bodies contain the records of his experimental work, it is to his addresses that we must turn to find the best expressions of a vivid personality which was a constant inspiration to those who knew him.

These addresses were models of arresting exposition, and constitute valuable contemporary records and reveal clearly how very much "worth while" he found metallurgy to be. The care with which facts of historical interest and importance were gathered from a wide range of sources shows the enthusiasm with which he sought, in the words I have already quoted, to open out ways for the escape of what he felt to be "imprisoned splendour." His passion for exactness is shown by the immense variety of footnotes and cross-references which in themselves constitute a valuable bibliography, while the careful choice of phrasing displays his literary skill and his acute sense of fitness. It would be quite impossible at this stage to attempt a review of these addresses. I can but mention a few of those which appear to me to be of outstanding interest.

Following the series of Cantor Lectures in 1884 on "Alloys Used for Coinage," to which I have referred, came three other series on alloys to the Royal Society of Arts in 1888, 1893, and in 1897.

His Friday evening discourses at the Royal Institution were triumphs of popular exposition of the matters which were of such absorbing interest to him. Accompanied as they always were by a wealth of experimental illustration—often daring in its character—they afforded him opportunities of actually demonstrating in public for the first time many of the notable advances in metallurgy. The subjects chosen for these discourses were respectively "Certain Properties Common to Fluids and Solid Metals" (1886), "Some Curious Properties of Metals and Alloys" (1888), "Metals at High Temperatures" (1892), "The Rarer Metals and Their Alloys" (1895), and "Metals as Fuel" (1901).

The two latter are of particular interest. At one he showed the operations of melting chromium, and of boiling silver, in an electric furnace (which had been constructed in his own laboratory), and also the reduction of the oxides of the rarer metals by granulated aluminium which had then recently been accomplished in this country by Claude Vautin and his assistant, H. K. Picard (one of Roberts-Austen's former students). The use of aluminium for this purpose, now, of course, common practice, was further demonstrated at the last of these discourses, and he expressed his indebtedness to Dr. Hans Goldschmidt, of Essen, for the loan of some remarkable specimens, and made the generous tribute that "it is through his labours that metallurgy enters upon an entirely new phase." What have since become known as "alumino-thermic processés" had their origin in this early work of Vautin and of Goldschmidt, who had acquired Vautin's patent rights.

Roberts-Austen's notable achievements in regard to art metal work found expression in numerous addresses. "The Colours of Metals and Alloys" was a subject of particular interest to him, and the discovery of the "Purple Alloy" of gold and aluminium in the course of work on these alloys in his laboratory in 1892 gave him great delight.

The varieties of "patinas" by which the Japanese metal workers had produced a range of beautiful tints on plaques and other objects attracted his attention and many reproductions of these were made. The Commemoration Medals issued by the Mint at the time of the Diamond Jubilee were "toned" by methods which arose directly from his earlier interest in these various forms of "patination."

Of his addresses, however, two are outstanding, and these came towards the close of his career. They were the presidential addresses which he delivered in 1899 and 1900 to the Iron and Steel Institute.

In the first, he gave an exhaustive review of the contributions made by Great Britain to the progress of the metallurgy of iron and steel during the nineteenth century, while in the second, delivered in Paris at the Autumn Meeting, he reviewed the contributions made by France during the same period. The circumstances accompanying the latter occasion were, in many ways, brilliant, coinciding as they did with the memorable exhibition of that year and attracting a representative gathering of metallurgists from all countries. His friend, Osmond, rendered his address into graceful French prose. It was perhaps characteristic of him that he should have chosen lines from Laurence Stern's "Sentimental Journey" with which to preface his remarks: "It is an age so full of light that there is scarce a country or corner of Europe whose beams are not crossed and interchanged with others, but there is none under Heaven abounding with more variety of learning, where the sciences may be more fitly wooed or more surely won than in France." Although these lines were written in 1768, the circumstances under which the Institute visited Paris in 1900 were, no doubt, such that he could truly say of this tribute, "We feel its justice and gladly adopt it as our own."

Many honours came to him, but I need not recite them here. They are recorded in the *Dictionary of National Biography* and elsewhere.

Henry Marion Howe, the distinguished American metallurgist and personal friend of Roberts-Austen, writing some years after his death, said: "The data which he recorded may be replaced by still more accurate and fuller ones. But his methods of presentation will retain their value unlessened, because they are adapted to the unchanging human mind. . . . The reason why on returning to London we went first to the Mint was that we met there one who welcomed us not for his own sake, but for ours; who was truly glad to put his researches off till night in order that he might quicken us. You felt instinctively that you drew inspiration from his look and presence and became better fitted for receiving whatever is uplifting and broadening in the world's metropolis."

Of the lighter and playful side of his personality I should like to have told you something—of his readiness at all times to supply a quip or rejoinder either from his own inexhaustible fund of humour or from the pages of Charles Dickens, of his inimitable gift of mimicry which was given full play at the frolics of the now legendary "Red Lions," which in those days followed the annual meetings of the British Association (of which he was General Secretary for four years).

Of a more serious nature was the active interest he took in the erection of a village church close to the Surrey home to which he and Lady Austen had looked forward to spending more of their time than had been possible hitherto. Here, as a diocesan reader, he frequently conducted the services. The attitude in which he approached his scientific investigations is shown, I think, by the concluding words of one of his earlier addresses: "We can be certain of nothing save the boundless munificence of the Creator."

If I have succeeded in giving you some slight impression of one who lived wholly for the progress of metallurgy, and who did much in his day and generation to stimulate others to share his enthusiasm and his conviction of how much more there was to come, I shall be content.

Practical Aspects of Industrial Furnace Insulation

By John W. Dawson.

The proper application of high-temperature insulating firebrick provides an easy and effective method of effecting economy in fuel; in addition, however, new economies and advantage are introduced, the most important of which is the saving of time. The author discusses hot-face insulation and gives some performance figures which are noteworthy.

DURING recent months there has been a spate of literature describing the advantages brought into being by the use of thermal insulating materials in various types of industrial heating equipment. Much of this literature might lead one to suppose that an extensive technical knowledge of this particular aspect of furnace building practice is an essential pre-requisite to the satisfactory use of such materials, and it is hoped that the following observations will help to dispel that illusion.

The developments in the technique of what has come to be known as "hot face insulation" have introduced new economies and advantages, one of the most striking of which is the saving of time. In fact, some of the results obtained by these methods are sometimes found to be difficult to believe, and there is no doubt that this very fact has been sufficient to deter some furnace operators from considering them.

In the past it was considered good practice to use insulating bricks and powders as a backing to furnace linings. This method certainly had the effect of reducing the amount of heat dissipated into the atmosphere from furnace walls and roofs, but, if the arrangement is considered carefully, it will be seen that it amounts to nothing more than enclosing the entire furnace within another furnace. In other words, the lining material simply becomes, in effect, an addition to the furnace charge. The heat generated therefore has to raise the temperature not only of the stock itself, but also of the lining and of the insulating backing. A pound of firebrick requires approximately a quarter of a British thermal unit to raise its temperature through 1° F.; one thousand standard 3 in. firebricks would need 2,000,000 B.th.u.'s to raise their mean temperature by 1 000° F. (528° C.).

Of course, in a furnace operating on a long cycle, this addition to the thermal capacity of the furnace fabric is not such a serious loss, but in those operating on short cycles the cumulative effect is extremely wasteful and will add considerably to the "weight of fuel per ton of stock" figures. In addition, however, the time required by such a furnace to reach working temperature will be strongly influenced by the thermal capacity of the lining and, correspondingly, temperature control will be sluggish, although this latter feature is often regarded as an asset, since it tends to stabilise temperature between fairly wide limits and to resist rapid fluctuation, particularly in the absence of modern methods of automatic control. Some builders of furnaces have deliberately gone to the extent of employing massive construction—as regards refractory linings—purely with a view to stabilising working temperatures, a method which may or may not have been laudable in the days of plenty, but certainly a very reprehensible practice under present circumstances.

In furnaces operating at temperatures above 950° C. the principal difficulty in using diatomaceous earth or other low temperature types of insulating brick, as a backing to the refractory lining, is the thickness of that lining which is necessary to reduce the temperature at the interface to a safe figure. Diatomaceous bricks, for example, must not be subjected to a temperature in excess of 950° C.; otherwise very severe shrinkage follows, with a consequent destruction of the insulating qualities of the bricks. The effect of an insulating backing is to cause the temperature in the lining to "build up" at the point of obstruction. The temperature fall, therefore, through the lining becomes more gradual and a very great thickness of firebrick, or other refractory, may be needed to reduce the interface temperature to 950° C. This introduces, or rather aggravates, the conditions discussed above; and tends to defeat the object of the insulating materials.

Readers will doubtless be aware of several cases in which no particular attention has been paid to this question of lining thickness with, apparently, no ill results. In such cases it will be found that the operating cycle of the furnace is so short that the lining never becomes saturated, but continues to absorb heat from the furnace and thus to protect the backing bricks. On the face of it, this state of

affairs may seem to be satisfactory. Certainly, no serious results have occurred, but, on the other hand, it is safe to say that little if any benefit has been obtained from the insulation. In the last two or three years, there have been numerous examples of breakdowns in furnaces which have been built to operate at high temperatures without particular regard to the thickness of lining necessary to protect the backing insulation. Most of these furnaces had previously given satisfactory results when operated on an 8-hour day basis. With the increase in working hours, however, the lining had reached saturation point and begun to overheat the backing. There is little doubt that this must have occurred in numerous furnaces, although in many cases the only immediate evidence of it would be a distinctly hollow sound when the lining is struck; that is, of course, the only evidence apart from an increase in fuel consumption, which, in the absence of meters or accurate check, may go unobserved.

There is no reason for furnace engineers being in any doubt as to the required thickness of lining, when using any particular type of insulator, as the manufacturers of such materials are only too glad to assist. Apart, however, from the question of protection of the backing insulation, another factor must come into consideration, from a practical point of view. It may, for example, be found that from the viewpoint of safety, so far as the backing is concerned, a 4½ in. lining of firebrick would be satisfactory. Such a thin lining, however, would be unstable mechanically, and it is not recommended that a refractory lining should be "tied" to a backing of low-temperature insulating bricks. Unequal thermal expansion would very soon sheer the headers used for this purpose. In such cases, therefore, a 9-in. lining is used, and consequently, for most purposes, this may be regarded as the minimum thickness of firebrick or other refractory used as a lining in connection with diatomaceous bricks. Thus, purely from considerations of a mechanical nature, the function of these bricks, which are, of course, extremely efficient under ideal conditions, is seriously hampered. It is an axiom of thermal insulating practice that all insulating media should be used as nearly as possible to their limiting temperatures. The object of this is to reduce the thermal capacity of the furnace fabric by eliminating unnecessary materials.

It will be seen from the observations made above that backing insulation, particularly in furnaces operating on long cycles, will save fuel by preventing the dissipation of heat into the atmosphere. Incidental to this saving, however, will probably be an increase—certainly no decrease—in the length of operating cycle, and an increase in the total dimensions of the furnace for a given hearth space, owing to wall thickness. Furthermore, when the furnace charge is withdrawn, a large amount of sensible heat will remain in the lining.

Hot-face insulation is calculated to overcome these difficulties, and this it certainly does very successfully. The term "hot-face insulation," however, is rather misleading, because it gives the impression that the type of brick used is suitable only as a furnace lining material under certain favourable conditions. This is very far from being the case, and there are numerous instances in which high-temperature insulating firebricks are giving excellent results as a backing to other refractories. High-temperature insulators usually have a maximum safe working temperature in excess of 1,300° C., and since this range covers a large part of the industrial heat-treatment operations, they can generally be used as a lining material except under very severe conditions, such as might be met in pulverised fuel or oil-fired furnaces. It is very important to bear in mind the significance of thermal conductivity figures for purposes of comparing one insulator with another. Table I will make this clear:—

TABLE I.

—	1st Quality Diatmoite.	2nd Quality Diatomite.	1st Quality H.T. Insulator.	Firebrick.
Thermal conductivity at 1,000° F. mean temp. in B.th.u.'s/ft.²/hr/1 in. thick 1° F. difference	1·25	1·5	1·35 1·60	8·00

The figures given in Table I are typical of those published by manufacturers. It will be seen that, although the three types of insulating brick have somewhat varying conductivity characteristics, such variations are only of an academic or laboratory significance when compared with the figures for ordinary firebrick. Other features, such as mechanical strength, resistance to abrasion, erosion and thermal shock should also be taken into account, quite apart, of course, from consideration of cost. A low-priced insulating material which will save a lot of fuel for a limited period is not so economical as one which will save fuel at a slightly lower rate for very long periods of time, even though its cost may be considerably higher.

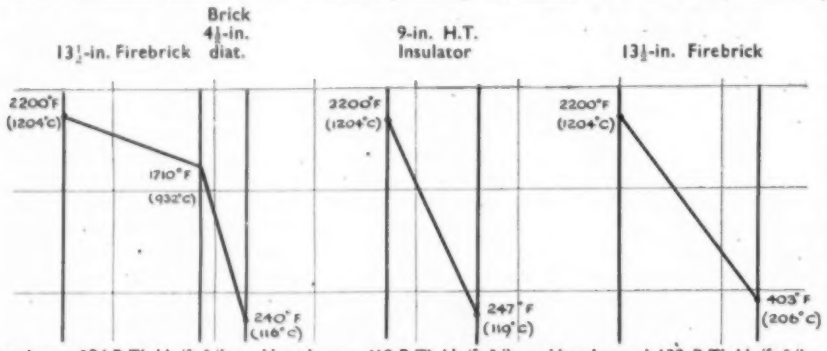
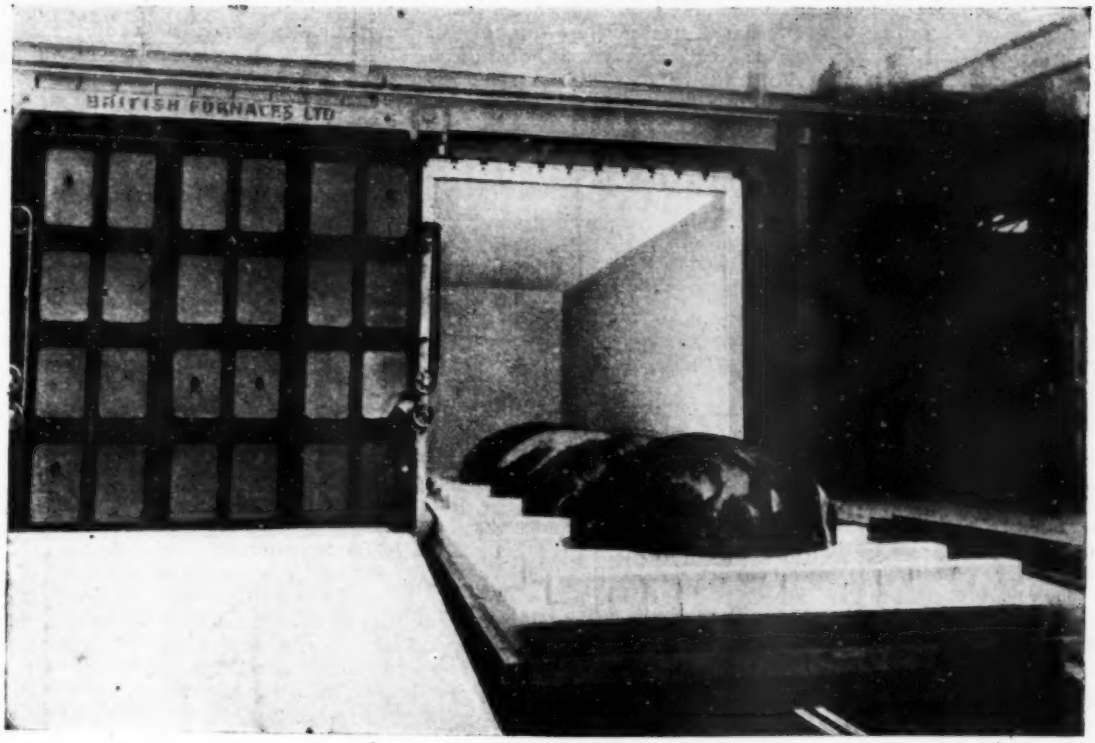

13½-in. Firebrick
Brick 4½-in. diat.
9-in. H.T. Insulator
13½-in. Firebrick
2200°F (1204°C)
1710°F (932°C)
240°F (116°C)
2200°F (1204°C)
247°F (119°C)
2200°F (1204°C)
403°F (206°C)
Heat Loss: 394 B.Th.U./ft.²/hr.
Heat Content: 80,700 B.Th.U. per square foot of superficial wall area
Heat Loss: 418 B.Th.U./ft.²/hr.
Heat Content: 10,100 B.Th.U. per square foot of superficial wall area
Heat Loss: 1,130 B.Th.U./ft.²/hr.
Heat Content: 51,350 B./Th./U. per square foot of superficial wall area

Fig. 1.—All examples under similar conditions of atmospheric temperature.

In those cases where hot-face insulation is applied, instantly the thermal capacity of the furnace fabric is greatly reduced. The dense firebrick lining is dispensed with and the light-weight insulating bricks reach a very much lower mean temperature than do firebricks with an insulating backing under similar conditions. Reference to Fig. 1 illustrates this by comparison of the two methods of applying thermal insulation.

It will be observed that the hot-face insulation scheme contrasts very strikingly with the backing arrangement as far as heat content is concerned. Heat losses, however, are similar in each case, and together show an enormous saving compared with a solid firebrick wall of conventional thickness.

The obvious conclusion, of course, is that high- and low-temperature insulators should be used in conjunction with each other as complementary components, whenever conditions permit. Here again, however, mechanical stability must have first consideration; theoretically, a wall comprising 4½ in. of high-temperature insulation with 4½ in. of low-temperature backing may appear to be ideal under certain circumstances, but it would prove to be unstable under working conditions. A far more satisfactory arrangement would be 9 in. of high-temperature insulation with 4½ in. of diatomaceous brick as an independent backing between the high-temperature insulators and the steel case of the furnace or the red brick outer wall. Indeed, 9 in. of high-temperature insulating brick alone would be very much more satisfactory than 4½ in. of each.



Courtesy of Daniel Adamson & Co., Ltd., and of British Furnaces Ltd.

Fig. 2.—Large stress-relieving furnace arranged with 9-in. high-temperature insulation, with 4½-in. diatomaceou brick as an independent backing.

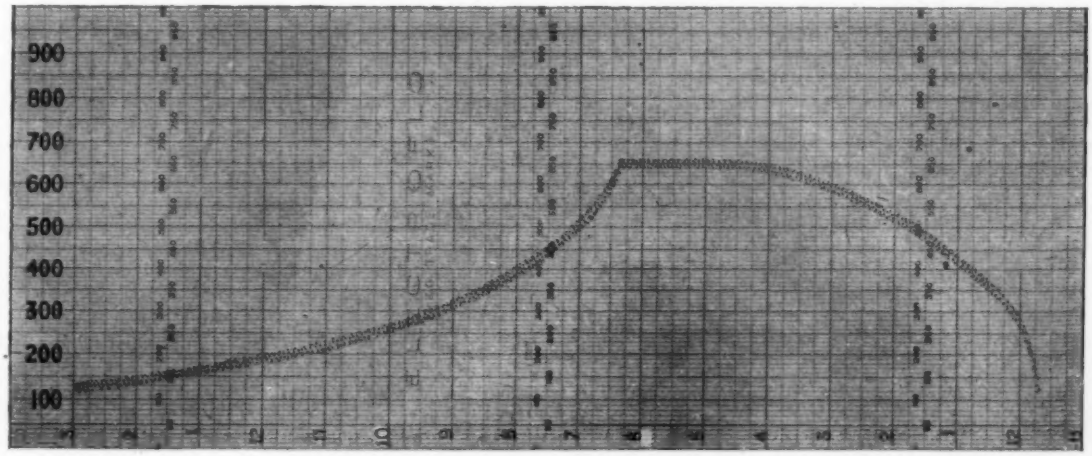


Fig. 3.—The temperature record of the above furnace which reveals the effects of this method of construction.

The large stress-relieving furnace illustrated in Fig. 2 makes use of the arrangement suggested. The 9 in. lining of high-temperature insulating firebrick has a 4½ in. backing of diatomaceous earth bricks and a glance at the temperature record chart (Fig. 3) will reveal the effects of this method of construction particularly when the unusually large size of the furnace is borne in mind. The internal dimensions are 36 ft. × 14 in. × 14 ft., and with a charge weighing about 20 tons the furnace is brought up to working temperature of 680° C. in 5 hours. During the whole operating cycle with this charge, the total fuel consumption is only 80,000 cub. ft. of town's gas. The furnace is easily capable of taking a charge more than four times as large as the one mentioned above, and under those conditions the performance would be even more excellent.

There are instances of furnaces previously lined with firebrick and subsequently adapted to hot-face insulation, in which this modification has reduced the time required to reach working temperature by 80%. Accuracy of temperature control has been greatly facilitated, with unusually even distribution of temperature. Cooling can, when required, be carried out with great speed or it may be retarded correspondingly, because of the reduction in thermal inertia brought about by elimination of the solid firebrick lining.

In furnaces working at very high temperatures or under very severe conditions, high-temperature insulating bricks, as explained before, may be used as a backing to a suitable thickness of firebrick or silica brick. In conjunction with firebricks, most H.T. insulators may be bonded or tied for

stability, since their thermal expansion characteristics are fairly similar. At very high temperatures, however, the effect of an insulating backing may be to overheat the lining. Its mean temperature may rise to the point where softening of the entire mass of the brickwork will commence, and care must therefore be taken to ensure that the lining is capable of withstanding the increased mean temperature to which it will be subjected. The under-load refractoriness test is, of course, the best indication of the potential behaviour of such a lining. Incidentally, this particular test which is so valuable in connection with nearly all refractory bricks is not very informative when applied to high-temperature insulating bricks, because, under working conditions, the temperature gradient through such bricks is very steep; although the face of the bricks may be at a temperature approaching that of their softening point, the remainder is very much lower, unless, of course, they are backed by a very great thickness of insulation and used in continuous furnaces operating at or near their maximum safe temperature.

At the moment, of course, it is not always practicable to consider the building of large numbers of new furnaces. The question is rather one of modifying existing installations and the fact that the use of high-temperature insulation requires even less space than ordinary firebrick construction means that furnaces already in existence can be insulated without encroaching on hearth space and without any considerable alteration to the general structure of the installation. In most cases it is good practice to spring the furnace arch from the insulating lining. By this mean a sound and gas-tight structure is achieved. There are, of course, numerous examples of furnace arches built of high-temperature insulating bricks and having a span exceeding 15 ft. Such arches give excellent results, and are to be recommended where furnace conditions permit.

Summarising, therefore, the correct application of high-temperature insulating firebrick constitutes an easy and effective method of obtaining fuel economy with, in most cases, other very considerable advantages. In all such applications the savings to be made are substantial whilst in certain favourable cases they are spectacular. Such results are usually most striking in connection with smaller types of furnace, where, in any case, the mass of the furnace fabric must be high in relation to the space available for the stock, since the wall thicknesses are, in turn, high in relation to the dimensions of the hearth space. The furnace illustrated above is, of course, a very large one, and the excellent performance figures shown will give some indication of the even better figures which may be expected from smaller furnaces similarly insulated.

The outstanding advantage of high-temperature insulation is the fact that little, if any, structural alteration is usually required for its application. Manufacturers of these bricks are in possession of a very extensive fund of knowledge and experience regarding their application, and if furnace operators would consult such manufacturers, they could hardly fail to make very sound contributions to the National Fuel Economy campaign, so vital at present and hardly less important in times of peace.

Dr.-Ing. L. Frommer

IT is with regret that we announce the death of Dr. L. Frommer, following an operation on January 27, 1943, at the relatively early age of 50, when he was on the threshold of the scientific achievement and recognition which were his greatest ambitions and for which he worked with such relentless energy.

Born of Polish parents, Dr. Frommer was educated and spent most of his life in Germany, where he studied under Prof. Dr. Georg Schlesinger. He was assistant to Prof. M. Polanyi at the Kaiser Wilhelm Institut für Physikalische Chemie in Berlin-Dahlem from 1928-1933. He was one of the first of Germany's scientific men to fall a victim to Nazi oppression, and came to Britain in 1934, where his first engagement was secured through the introduction of Mr. W. C. Devereux, whom he met in 1929. Subsequently he was engaged as a consultant by High Duty Alloys, Ltd., at first on die-casting and then on the development of methods for the measurement of internal stresses in aluminium alloys through the medium of X-ray crystallography. Shortly afterwards, in 1936, he joined the permanent staff of that company as Research Metallurgist.

In addition to X-ray crystallography, two other projects had been initiated—viz., spectrographic analysis and colorimetric analysis—and he was given the task of applying all these to the routine testing of light alloys. Thus, he had in his charge three embryo departments and a huge programme of work; those on spectrographic and colorimetric analysis were the first to be completed, and the departments were handed over for routine analysis. In X-ray physics and metallurgy he built up a laboratory for the measurements of stresses in industrial light alloy components, and adapted to these coarse-grained materials the methods previously used only for steels and other fine-grained materials. This work was of great practical value in connection with the development and improvement of manufacturing methods. He was also engaged in research work on the problems of strain, plastic flow, and fracture of metals. In addition to this, of course, he handled day-to-day work of the X-ray physicist—problems of cold work crystal texture and orientation, identification, etc. In 1939 he was given the additional task of investigating the internal friction of light alloys. He developed a technique which incorporates many novel features and which has afforded much information of both scientific and practical interest. It is unfortunate that most of his work on these two subjects remain unpublished at the time of his death. The work on these researches will be carried on by the departments which he organised so ably, and the results of his work will be published with the least possible delay. His published works include: "Handbuch der Spritzgusstechnik," published in Berlin, 1933; "A New Method for Measuring the Rate of High Velocity Gas Reactions," with M. Polanyi, published in the Transactions of the Faraday Society, July, 1934; "The Estimation of Cold Work from X-ray Diffraction Patterns," published in the *Journal of the Institute of Metals* in 1939; "Discussion on Industrial Application of Spectrography in the Non-Ferrous Metal Industry," published in the *Journal of the Institute of Metals* in 1939; and "Notes on an X-ray Investigation into Cold-Rolled Magnesium Alloy Sheet," published in the *Journal of the Institute of Metals* in 1941.

His impatience to get results and his extraordinary attention to detail became a by-word amongst his colleagues. He was a prodigious worker, never sparing himself, and many will regret the passing of so able a man.

Mr. F. G. Smith

IT is with great regret that we announce the death on March 1, 1943, of Mr. Frederick George Smith, M.I.Mech.E., Director of the Wellman Smith Owen Engineering Corporation, Ltd., at his residence at "Wayside," Foxley Lane, Purley, Surrey.

Mr. Smith had been associated with the Wellman companies for over 30 years, and was a director and technical manager of the present Wellman Corporation from its formation. His help and advice will be greatly missed, and his early death mourned by a large circle of business friends.

Professor F. C. Lea, D.Sc., M.Inst.C.E., has been appointed President of the Institution of Mechanical Engineers. He is a director of Edgar Allen and Co. Ltd.

A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts

THIS report constitutes a summary of data resulting from the metallurgical examination of German and Italian aircraft engine and airframe parts by the Aero Components Sub-Committee of the Technical Advisory Committee to the Special and Alloy Steel Committee formed for this purpose. In this, the final of this series, is presented a summary of the results of investigations on a number of miscellaneous components, including a pipe from an exhaust system, control chains, gun mounting parts, and bomb release mechanisms.

The Sub-Committee responsible for these investigations and for this report comprise Mr. W. H. Dyson, Ministry of Aircraft Production; Dr. H. Sutton, Royal Aircraft Establishment; Dr. R. Genders, Superintendent, Technical Applications Metals, Ministry of Supply; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd.; Mr. H. H. Burton, The English Steel Corpn., Ltd.; Mr. W. J. Dawson, Messrs. Hadfield, Ltd.; Dr. W. H. Hatfield, F.R.S., Chairman, Brown-Firth Research Laboratories; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.; Dr. T. Swinden, the United Steel Companies, Ltd.; and Mr. G. Stanfield, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out from the beginning of the war until towards the end of 1941, but investigations have continued and are still in progress, and the work is being carried out meticulously. Naturally, no comparisons are made in the report with corresponding parts in British or American aircraft, neither are certain aspects, which the investigations have shown to be open to criticism, emphasised.

Section XIV.—Miscellaneous Parts

IN this section a number of miscellaneous components which were examined together are considered individually.

A.—Inner Pipe, Inlet Heater from Exhaust System of Heinkel 111H Aircraft (Report No. 10)

The pipe had been removed from inside the exhaust pipe of the Jumo 211A engine, installed in a Heinkel 111H aircraft. Air for cabin heating was drawn through the pipe. The pipe was $2\frac{3}{4}$ in. o./d., and had been made by bending sheet 0·060 in. to 0·062 in. thick and gas-welding along a longitudinal seam.

The steel was of the following chemical composition:—

	%		%
Carbon	0·13	Chromium	18·07
Silicon	0·68	Molybdenum	0·25
Manganese	0·38	Copper	0·17
Nickel	8·86	Titanium	0·62

It will be noted that the material was a titanium bearing 18/8 chromium-nickel-austenitic steel containing small and possibly accidental additions of molybdenum and copper. The weld metal was not fully resistant to intercrystalline corrosion when subjected to the standard acid-copper-sulphate test.

B.—Control Chains from Heinkel 111A (Aircraft Report No. 11)

Samples of 8 mm. and 0·500 in. pitch chain were examined. They were found to be commercial products, the smaller one being of the type used for general industrial purposes, and the larger principally for motor-cycle transmission. The chains were of normal design, except that the 0·500-in. chain had plain unshouldered bearing pins and no provision for locking the bushes.

As regards the materials, the following departures from British practice were found:—

8 MM. CHAIN.

Part.	German.	British.
Bearing pin	C.H. 3% Ni, 0·7% Cr steel	C.H. mild steel.
Bush	C.H. 1·5% Ni steel	C.H. mild steel.
Roller	C.H. 2·5% Ni, 0·2% Mn steel	C.H. mild steel.
Plates	H. and T. 0·5% C, 1·0% Si, 0·5% Mn steel	H. and T. 0·65% C steel.

0·500 IN. CHAIN.

Part.	German.	British.
Bearing pin	C.H. 3% Ni, 0·7% Cr steel	C.H. 2% Ni steel.
Bush	C.H. 1·5% Ni steel	C.H. mild steel.
Roller	C.H. 2·5% Ni, 0·2% Mn steel	C.H. mild steel.
Plates	H. and T. 0·57% C, 1·3% Si, 0·45% Mn steel	C.H. 0·75% C steel.

The wide use of alloy steels is surprising. The weight per foot of the 8 mm. chain was slightly greater than that of the corresponding British product, but the 0·500 in. chain was about 56% heavier.

C.—Gun Mounting Parts from Messerschmitt Me 110 (Report No. 52)

The parts examined consisted of: (1) Port machine-gun tube, (2) forward gun mounting, and (3) rear gun mounting.

1. *Port Machine Gun Tube.*—This consisted of a steel tube approximately 65 mm. o./d. and 62·5 mm. i./d., carrying a welded flange riveted at an angle of about 20° to an aluminium alloy sheet, which formed part of the covering on the nose of the aircraft (Fig. 1).

2. *Forward Gun Mounting.*—The steel employed for both parts was of the 0·25% carbon, 1% chromium, $\frac{1}{4}$% molybdenum type. The parts had been built up by gas welding in sheet and tube, and none of them had been heat-treated after welding (Fig. 2).

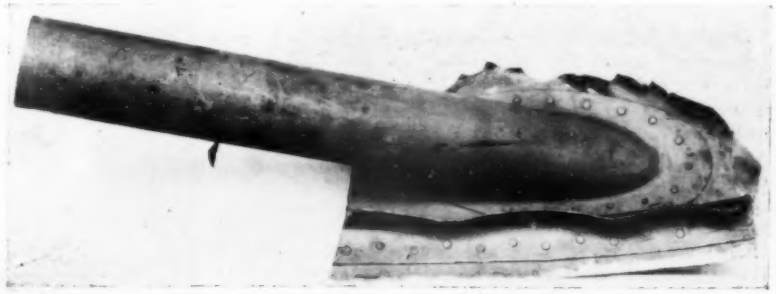


Fig. 1.—Port machine-gun tube—Me 110.

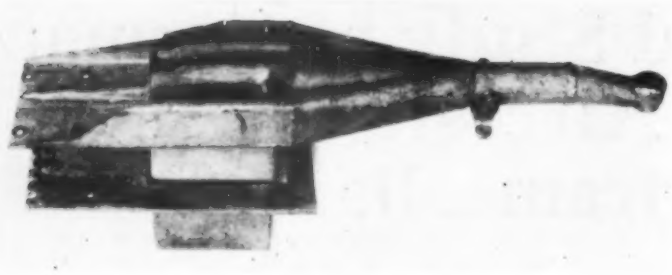


Fig. 2.—Forward gun mounting—Me 110.

3. *Rear Gun Mounting.*—The mounting is shown in Fig. 3, after removal of the cap, whilst Fig. 4 shows the approximate assembly of the component parts. The steel used for the main parts was found to be of the 1% chromium, ¼% molybdenum type in either the softened or hardened and tempered condition. A considerable amount of welding had been done on the softened parts, but none of the welds appeared to have been subsequently heat-treated. The chromium-molybdenum steel had evidently been made by the basic electric process, whilst the remaining steel parts were in plain carbon steel of open-hearth manufacture.

Hardness tests, chemical analyses, and microscopical examination revealed no unusual metallurgical feature. All the steels were of the plain carbon type, and probably of open-hearth manufacture. The hook was a drop stamping in 0·45% carbon steel in the "as forged" condition. Only the bolt, about which the hook pivoted, was hardened and tempered.

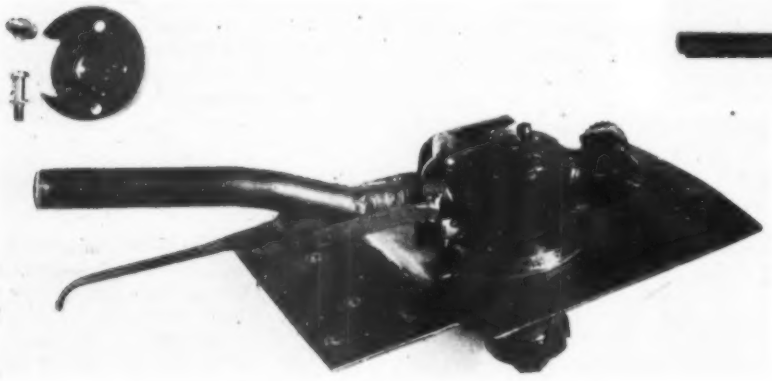


Fig. 3.—Rear gun mounting—Me 110.

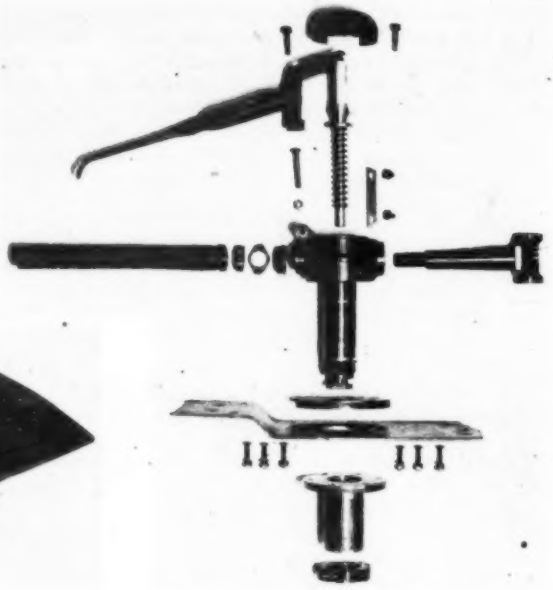


Fig. 4.—Details of rear gun mounting—Me 110.

D.—German Bomb Release (Report No. 31) and Bomb Hooks (Report No. 32)

A view of the complete apparatus, which was of the electric-magnetic type, is shown in Figs. 5 and 6. For details of the mode of operation reference should be made to the original report.

Fig. 7 shows the loaded position. The passage of current through the solenoid caused a clockwise movement of the brass trigger T, which depressed the arm A of the lever pivoted at B. The resulting upward movement of the other end of the lever which carried a small roller released the prong P. On release this prong moved forward and this movement was transmitted through levers to the bomb hook H, which, by assuming a more vertical position released the bomb.

Bomb Hooks

Two bomb hooks, one from a vertical carrier (250 kilos.) and one from a light series carrier (up to 50 kilos.) were examined.

The larger hook had been made from air-hardening nickel-chrome steel, probably blanked from plate and hardened and tempered to a tensile strength of about 88 tons per sq. in. The smaller hook had been made as a drop forging in 0·5% carbon steel and left in the "as-forged" condition.

E.—Cartridge Release Mine-layer (Report No. 33)

The component consisted of a light alloy housing containing a toggle arrangement designed to open and close the jaws. Fig. 8 gives a view of the bottom end, while Fig. 9 shows the working parts removed from the housing.

In the closed position the upper toggle levers E and F are practically in line, the tension spring J forcing the arms upward, which closes the jaws G and H. When the trigger C is pressed the cam B fixed to the trigger shaft is moved downwards and the spring pulls the top portions of the jaws inwards, thereby opening the jaws.

The housing was an aluminium alloy

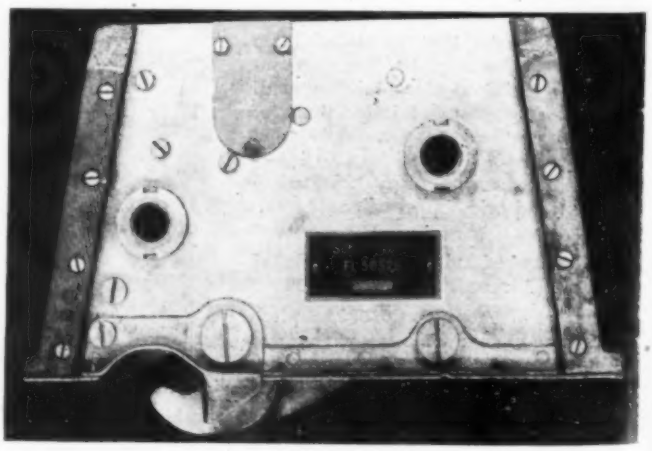


Fig. 5.—Bomb release apparatus of the electric-magnetic type.

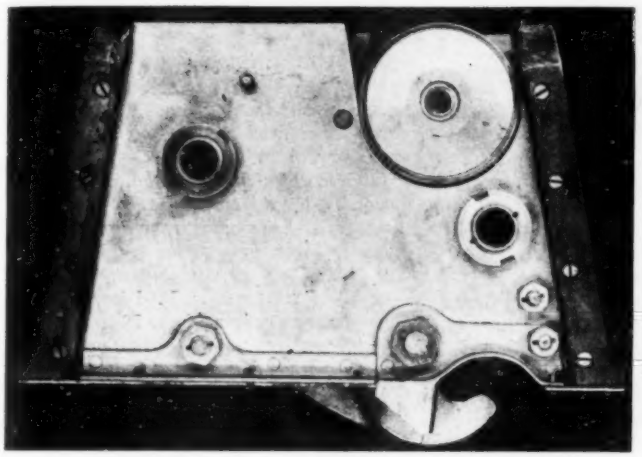


Fig. 6.—The reverse view of the bomb-release apparatus.

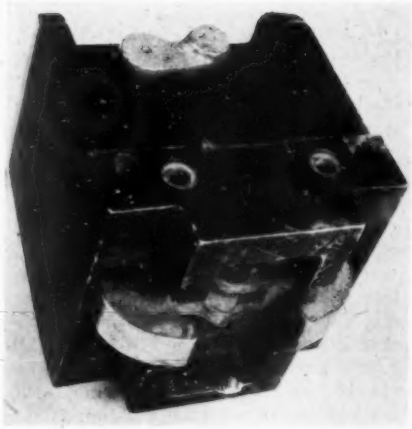


Fig. 8.—Bottom end of a cartridge release mine-layer.

casting of very poor quality containing 4·63% of magnesium and 0·86% of silicon.

The parts have been lettered as follows :—

A. Tubular bearings.
B. Cam operated by trigger.
C. Trigger.
D. Nut at end of trigger shaft.
E. Lever arm I.
F. Lever arm II.
G. Jaw I.
H. Jaw II.
I. Cam spring.
J. Toggle lever spring.
K. Four pins.
L. Small pin.
M. Roller at end of cam.

Parts A, B, C, E, F, G and H had been cadmium-plated. With the exception of parts L and M the components were chemically analysed, and the results are shown in the following table.

The tubular bearings, cam, trigger and lever arms had all been made in 1% chromium-molybdenum steels with carbon contents ranging from 0·29% to 0·42%. The jaws were of air-hardening nickel-chromium steel.

Microscopic examination of sections revealed that with the exceptions of the lever arms and trigger nut all the main

ANALYSIS OF COMPONENTS IN THE CARTRIDGE RELEASE MINE-LAYER.

	A. Tubular Bearing	B. Cam.	C. Trigger.	D. Nut.	E. Lever Arm I.	F. Lever Arm II.	G. Jaw I.	H. Jaw II.	I. Cam Spring.	J. Lever Spring.	K. Pin.
Carbon	0·29	0·31	0·27	0·55	0·42	0·39	0·40	0·39	0·82	0·91	0·32
Silicon	0·26	0·29	0·33	0·35	0·37	0·35	0·25	0·25	0·10	0·08	0·44
Manganese	0·65	0·62	0·55	0·92	0·65	0·65	0·41	0·41	0·62	0·23	0·40
Sulphur	0·012	0·009	0·006	0·144	0·026	0·024	0·009	0·009	—	—	0·006
Phosphorus	0·012	0·016	0·017	0·019	0·028	0·027	0·011	0·011	—	—	0·009
Nickel	0·014	0·013	0·17	Trace	<0·02	<0·02	4·38	4·39	<0·02	<0·02	1·61
Chromium	1·07	1·02	1·15	Trace	1·03	1·05	1·44	1·44	0·02	0·04	2·52
Molybdenum	0·12	0·22	0·24	Nil	0·25	0·20	0·06	0·05	Nil	Nil	0·64
Copper	0·10	0·15	0·13	—	0·11	0·12	0·18	0·18	—	—	0·20
Vanadium	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·12
Oxygen	—	0·0029	0·0026	—	0·0015	0·0018	0·0027	0·0026	—	—	—
Hydrogen	—	0·00011	0·00005	—	0·00012	0·00012	0·00008	0·00008	—	—	—
Nitrogen	—	0·0122	0·0110	—	0·0073	0·0035	0·0107	0·0090	—	—	—

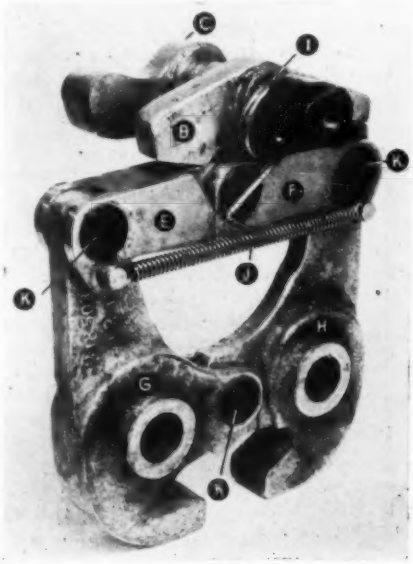


Fig. 9.—Showing the working parts of the cartridge-release mine-layer.

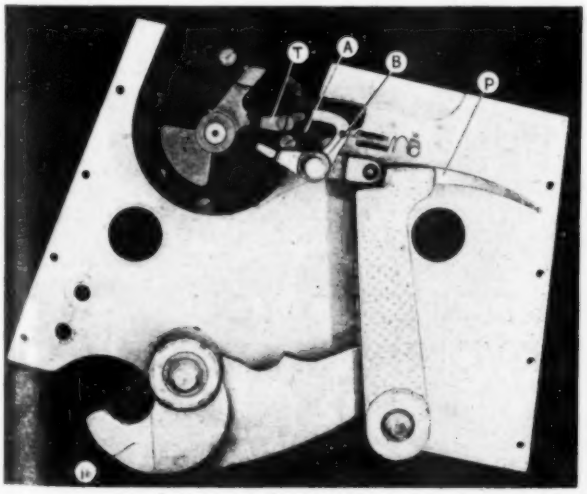


Fig. 7.—Showing the bomb release mechanism in the loaded position.

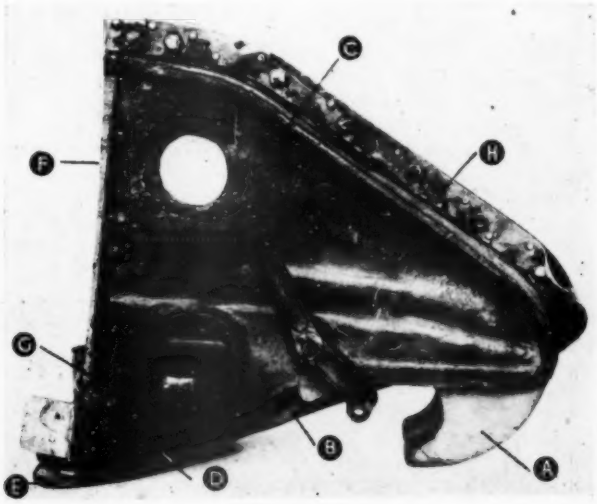


Fig. 10.—Assisted take-off hook—He 111.

steel working parts had been made from high-quality basic electric steel, with the exception of the lever arms which were probably made from Siemens' steel, and the trigger nut of free-cutting steel.

The two springs were made of plain carbon steel of high quality, and all the main parts had been hardened and tempered to hardness values in the region of 300 to 400. An unusual feature observed during the hardness tests was that the hardness of the parts was appreciably higher at the surfaces than in the cores, possibly this was due to the parts having been heated in a cyanide bath prior to hardening. No marked carburised zone was found.

Tensile tests on the lever arms gave tensile strength values of 80 and 85 tons/sq. in. with 12½% elongation on $4\sqrt{A}$. The tensile strength of the jaws was nearly 90 tons per sq. in. with 17% elongation on $4\sqrt{A}$.

The cam trigger lever arms and jaws had all been made as drop forgings.

F.—Assisted Take-off Hook from Heinkel 111 (Report No. 34)

The hook as received is shown in Fig. 10.

The main body of the assembly consisted of a triangular casting (see also Section X—Castings) with two parallel hooks (A) on the front of the underneath face (B); top (C), bottom (D) and back (E) flanges, rear plate (F), and stiffener (G), and a top rib (H). The swivel pin fitted through the lower broader section of the casting, and was held in position at each end by a large nut and retainer clip. The levers were pivoted at each side of the casting, on a thin pin which fitted through the lower broad section of the web at a central position. One end of each lever passed through slots in the bottom flange, and the other end was held by tension springs attached to eye-bolts on the rear plate of the casting. Along the top rib, bottom of the rear plate, and the back flanges were remnants of the non-ferrous material of the fuselage, to which the assembly had been bolted.

The main body of the hook was a steel casting in 0·26% carbon, 1% chromium, and 0·25% molybdenum steel, manufactured in the basic electric-arc furnace. The casting was generally sound, and its surface was good. Some building up with weld metal had been done, and filler rod of a similar chemical composition had been employed. The casting was in the normalised condition, and a tensile test gave a maximum stress value of 59 tons per sq. in., with 18% elongation on $4\sqrt{A}$. Izod impact tests gave values ranging from 28 to 35 ft.-lb.

The swivel pin and levers (which were drop forgings) had also been made in 1% chromium-molybdenum steel of basic electric-arc quality. The levers had been hardened and tempered, and a tensile test gave a value of 68 tons per sq. in. for ultimate stress, with 23% elongation on $4\sqrt{A}$.

The lever pin and the springs were in open-hearth quality plain carbon steel. The springs were in the "as-drawn" condition and had a diamond pyramid hardness of 505.

From the Editor

At the request of the Aero Components Sub-Committee of the Technical Advisory Committee, we are publishing the above report on German and Italian aircraft engine and airframe parts in book form, and crediting the Royal Air Force Benevolent Fund with all profits from its sale.

The work covered by the report is really a summary of very extensive investigations which have been carried out meticulously and at great cost. Essential information arising from the study of components is presented in a concise and readily assimilated form, and the text is supported by numerous illustrations, which, in themselves, convey valuable information to the initiated.

We, the publishers, have agreed that the whole of the amount arising from its sale, apart from the actual cost of printing, binding, and distribution, will be credited to the Fund, but in order that the maximum sum may become available for this purpose, we are seeking orders for the book in advance of its publication. This will enable us to estimate more accurately the number of copies needed before we go to press, and thus limit the number of surplus copies—a waste which would reduce the amount to be credited to the Fund.

Apart from the fact that the book is of considerable value as a technical study, and as such is published at a relatively low cost, its sale will help a very deserving cause. In a letter from Lord Riverdale, Chairman of the Appeals Committee of the Royal Air Force Benevolent Fund, he states: "Over 22,000 names are on our books at the present time, and as the raids spread and with greater magnitude into enemy country our responsibilities increase."

The preparation of the book is well advanced, but it is not yet possible to give a publishing date; you may be assured, however, that there will be no unnecessary delay, and orders will be executed as soon as copies are ready. It will comprise about 160 pages, be 9 in. × 5¾ in. in size, and worthily bound. The price has been fixed at 10s. 6d. net.

May we ask your co-operation in making this a really worth-while effort by sending an order for your copy *now* to METALLURGIA, 21, Albion Street, Manchester, 1, England.

HELP YOURSELF AND IN DOING SO YOU HELP THE R. A. F. BENEVOLENT FUND

If you have already been advised of the publication of this book through other sources, please accept our apologies and believe it is due entirely to our enthusiasm for the success of the venture.

Powder Metallurgy: Its Products and Their Applications

By W. D. Jones, M.Eng., Ph.D.

The popularity of powder metallurgy depends upon its application in the manufacture of metal parts possessing properties which cannot be obtained by any other process, and by the fact that, frequently, it is more convenient or cheaper to use the technique than other methods of manipulation. In a recent paper, before the North-East Coast Institution of Engineers and Shipbuilders, Dr. Jones considered some of the advantages of powder metallurgy and gave examples in which the technique is applicable in marine engineering, which are reproduced here in a substantially abridged form.

IN general, there are three principal possible advantages of the powder-metallurgy technique which are responsible for its growing popularity—viz. :—

1. It is frequently possible to manufacture metal parts which have shapes or properties which cannot be achieved in any other fashion. Examples of this technique are the porous bearing, filter, or wick, the bimetal contact material, and the hard metals.

2. It is often more convenient to use the metal-powder technique than methods of casting. Cases of this technique are the manufacture of tungsten, molybdenum, platinum, the Alnico magnet, and impregnated diamond tools.

3. It is frequently cheaper to use the power metallurgy method, and in many cases is a better all-round manufacturing proposition. Examples of this are the various small iron parts which are now being made in America.

The manufacture of bearings in porous bronze is well established in this country, and they are extensively employed. The porosity of these bearings normally varies between 25 and 40% by volume, and is susceptible of very exact control in manufacture. In many cases the amount of oil which they retain is sufficient for their normal life, although of course they can still be fed with oil in the usual way, in which case the pores act as a capillary filter for solid foreign particles. These bearings are particularly economical in oil, and one important advantage which is claimed for them is the fact that a continuous lubricating film always exists over the whole bearing surface even before rotation of the shaft commences.

The successful manufacture of these bearings is not a simple matter. The process commences with copper and tin powders made to very carefully drawn up specifications. Generally, the particle size is of the order of 200 to 300 mesh, and they are mixed together in a 90/10 proportion. Some manufacturers add a small percentage of powdered graphite and others a small percentage of a lubricant to facilitate the pressing operation. Various types of presses are employed. The development of this industry took place, using a slow-speed hydraulic press, and this type is still employed for the largest sizes of bearings. The normal manufacturing output of to-day, however, comes from high-speed mechanically operated presses of the type which have been so much employed in the pharmaceutical industry for manufacturing tablets and pills, etc. Such presses are of the eccentric, cam-operated, or rotary type. They have to provide for rapid operation up to 500 pieces per minute, automatic feed of the correct weight of powder, pressing, and automatic ejection.

The compacts on ejection from the press are quite strong enough to handle, and must now be heat-treated or sintered. The furnaces employed are developments of the usual type of continuous brazing of bright annealing furnace. A protective atmosphere is maintained in the furnace, and it is possible to use atmospheres such as hydrogen or cracked ammonia; it is nevertheless generally considered necessary to turn to a cheaper atmosphere—namely, combusted coal gas. During the sintering or fritting operation the tin melts and gradually alloys by diffusion with the copper, producing a comparatively strong, but porous mass of bronze.

One of the most important advantages possessed by the powder metallurgy technique is that articles can be made exactly to size and shape without machining. This means, of course, working to customers' tolerances, but standard stocks of such bearings in the form of plain bushings generally have limits on internal diameter and outer diameter of minus 0·001 in. up to 1½ in. internal diameter, and limits on length of plus or minus 0·005 in. up to 1½ in. length. Closer tolerances are met for special requirements. During the sintering stage dimensional changes occur which may be either a growth or a shrinkage, generally the former, and one of the difficulties in manufacture is the close control of these changes. In practice, it means a very careful control over the quality of the powder, the composition of the mixture used, the pressing operations, and the time and temperature cycle in sintering.

On much the same lines porous bronze compacts are being manufactured and sold as filters for various solutions. Bronzes, copper-nickel alloys and pure nickel are being used for this purpose. The porosity varies over a wide range, and may reach 80% by volume. They are used not only in the chemical industry, but in domestic refrigerators and domestic oil heaters. One filter some 5 in. long and 2 in. in diameter has been developed as the fuel filter in a Diesel engine. Also, much on the same lines, bearings and valve guides are being manufactured out of iron powder and mixtures of iron powder and copper.

Hard Metals

The familiar hard-metal carbide tool of the type of Wimet, Ardoloy, Cutinat, Tecometal, etc., is made entirely by powder metallurgy. The manufacture of these materials is very difficult and complex, and every stage has to be accompanied by the most rigid scientific control. Compositions vary very considerably, but by far the greater quantity produced consist of tungsten carbide with or without a proportion of titanium carbide, together with a proportion of binding or auxiliary metal (generally from 3 to 13%), which is usually cobalt, with or without proportions of nickel or iron. In America, tantalum carbide is being used to a considerable extent. Tungsten carbide can of course be melted and cast, even though the melting-point approaches 3,000° C., but it has been found that a product made in this fashion is useless as a cutting tool.

An outline of the method of manufacture of the simple tungsten carbide tool bonded with cobalt is as follows :—

1. Making the powders which involves the preparation of pure tungsten oxide from the ore and reducing it in stages by heating in hydrogen until a pure tungsten powder of the right grain size distribution and qualities is obtained.

The tungsten powder is then mixed with suitable carbon powder and heated in hydrogen in a carbon tube at a temperature approximating 1,500° C. The product is tungsten carbide powder, although it is not necessarily pure after the first carburising operation. Along similar lines, by reduction of the oxide by hydrogen, cobalt powder is made, and again much care must be taken to obtain a powder having suitable chemical and physical properties.

2. The two powders are mixed in the desired proportions and ball-milled together for considerable periods of time to ensure very thorough incorporation of the cobalt with the carbide. Next, the two powders are pressed under hydraulic presses in suitably shaped dies generally arranged to form rectangular bars. A small proportion of paraffin wax dissolved in a suitable solvent is added to the powder before compression. This considerably aids compaction and produces pressed sticks that are just strong enough to be handled.

3. The sintering operation is divided into two stages: the pre-sintering and the final sintering. The first stage is conducted in hydrogen in tube furnaces at a temperature of approximately 800° C. In this pre-sintering stage one can regard the change taking place in the material as a sintering of the cobalt only. The product after cooling is then found to be reasonably strong, at least sufficiently strong to permit of its being shaped by cutting with carborundum discs, or by the usual operations of turning, drilling, or filing. In cutting the pre-sintered bars to shape, it is necessary to make careful allowance for the shrinkage that takes place during the final sintering stage, and which may amount to 20%. It is necessary to make this allowance as accurately as possible because, of course, the finished material is much too hard to be sized and any final adjustment in dimensions has to be made by expensive and laborious grinding operations. The final sintering takes place in hydrogen at a temperature of 1,400° to 1,475° C., depending on the composition. This is a delicate operation, requiring great attention to detail. Such a high temperature necessitates the use of special furnaces, and these are generally either carbon tubes heated by the direct passage of current, or alundum tubes wound with tungsten or molybdenum wire maintained in a hydrogen atmosphere. The temperature control of the furnace must be very exact, and the hydrogen atmosphere has to be extremely pure and dry. Finally, the sintered tips are brazed to the tool-holder and are then ground to size and polished (frequently by the use of a diamond impregnated lapping wheel, which is also a product of powder metallurgy).

Contact Materials

The modern contact material is a very fine example of powder metallurgy. Successful electrical contact materials are required to possess a formidable range of qualities. They should embody in the one alloy high electrical and thermal conductivity, high melting point, high hardness and wear resistance, low contact resistance, low vapour pressure, resistance to formation of tarnish films, and resistance to welding and formation of pits and beads caused by arcing, or transfer of metal from one contact to the other. There is no known cast metal or alloy which has any pretension of being able to meet all these requirements at one and the same time.

Magnets

The Alnico magnet is also a very good example of the modern powder-metallurgy technique. The composition is somewhat variable according to the grade and manufacture, but in general runs 9 to 13% aluminium, 17 to 24% nickel, 5 to 12% cobalt, sometimes copper, and the remainder iron. This composition is a most undesirable material to melt and cast, and the situation is made much worse by the fact that these magnets are frequently required in very small sizes (weighing as little as 0·15 grm.) and often in very complicated shapes. Moreover, the alloy has a high melting point, in the neighbourhood of 1,500° C., is very sticky and sluggish when molten, and it is also very difficult to prevent the aluminium from being lost by oxidation. The cast alloy is mechanically weak and easily broken in shaping and, in addition, is far too hard to be shaped otherwise than by grinding. It is not difficult to understand, therefore, that once this magnet material became popular attempts were soon made to manufacture it by the methods of powder metallurgy.

The process of manufacture follows very closely the lines of that used for hard metals, with modifications suited to the special compositions and the necessity of producing specific magnetic properties. In this manner the powder-metallurgy technique is able to solve a problem, which in some cases is acutely difficult to solve with a casting method. Furthermore, additional advantages are claimed for the powder magnet. In the first place, no casting method can approach the degree of accuracy with which the composition can be controlled by powder metallurgy. Secondly, the sintered magnet does not suffer from coarse crystalline growth which renders the cast magnet weak; thirdly, the sintered magnet does not suffer from typical casting defeats, such as blow-holes, cold sheets, cracks, or segregation of impurities to the grain boundaries; and lastly, the dimensions of small sizes can be very closely controlled, and any grinding that may have to be undertaken is very much less than that associated with the cast magnet.

Refractory Metals

Further examples of circumstances in which it is more convenient or better to use powder metallurgy technique than casting, are afforded by the refractory metals, such as tungsten, molybdenum, tantalum, platinum, etc. All these materials can be cast, but it is an expensive and difficult technique in view of the high melting points, and in many cases the cast product is certainly not so satisfactory as that made from powders. It is noteworthy that platinum has been worked up by powder metallurgy from the earliest days, and the details of the process were described by Wollaston in 1829.

Tungsten metallurgy is a typical example of powder metallurgy applied to the refractory metals. The tungsten powder, having very carefully controlled chemical and physical qualities, is reduced from the oxide by heating in hydrogen. The powder is pressed under hydraulic presses into bars from 8 in. to 24 in. in length and normally 10 mm. × 10 mm. in cross-section. The bar is then pre-sintered in hydrogen at 900° to 1,100° C. for half an hour. This treatment is given solely to increase the strength sufficiently to permit the manual handling for the next stage, which is the final sintering operation. This operation is conducted by mounting the bar between water-cooled contacts in an atmosphere of hydrogen, and an alternating current is passed through it sufficient in intensity to raise the temperature nearly to the melting-point. A normal bar requires a current of some 2,100 amps. at 10 to 15 volts for a period of some 30 mins. The temperature is controlled by regulation of the wattage employed. During sintering, shrinkage to the extent of some 17% occurs. After sintering, the bar is strong, but very brittle, and cannot be deformed at room temperature without fracture. It can, however, be manipulated in the neighbourhood of 1,300° C., and is, in fact, subsequently brought down to the dimension of a wire by hot swaging at about this temperature. Other complicated mechanical and thermal processes follow to produce the remarkable single crystal "coiled-coil" filament which is so familiar.

General experience gained with powder metallurgy, and in particular with the refractory metals, has shown that it is a technique which is particularly suitable for the working up and consolidating of metals in mass (as distinct from the manufacture of articles). The advantages of powder metallurgy are familiar to the workers in refractory metals, but are only just beginning to be appreciated by the

metallurgist handling the everyday metals—iron, nickel, copper, etc. It is an interesting speculation whether the metallurgy of the commoner metals will become powder metallurgy. There are indications that this is taking place, and one recent example is the coalescence process for copper, which is no more than a method of extraction metallurgy for extracting and working copper from its ores ; but it is powder metallurgy pure and simple, and inasmuch as the product appears to have improved qualities with respect to electrical conductivity, ability to absorb cold work, and freedom from casting defects, it is a technique which is likely to develop and extend in the future.

Dr. Jones next considered the field of powder metallurgy where, apart from other reasons and advantages, it is actually a cheaper technique than most methods. This field is best illustrated by the manufacture of a number of various small iron parts which is being undertaken on a considerable scale in America.

Iron Parts

Saving in manufacturing costs by using powder metallurgy is mainly achieved at the present time in cases where the die costs and the metal powder costs can be more than offset by the production of large numbers of parts in which, normally, a considerable amount of skilled machining is required. The iron parts referred to are more or less non-porous, or have a low porosity, and are not to be considered as bearing materials, although they are frequently given self-lubricating properties by oil impregnation or addition of graphite. Typical of such parts are a tappet from a washing machine, a part from a push-button radio tuner, a part in a dictating machine, a non-squeaking part from an automobile window winder, and an automobile oil-pump gearwheel. This last item is a remarkable achievement, and has received considerable publicity. It is a small gear used to circulate the oil in a General Motors car. The gear teeth must be true involute curves and accurately formed to avoid noisy operation or binding. In the past it has been machined from a cast blank at considerable expense. The powder metallurgy product is in every way superior and cheaper. A large number of advantages have been cited in its favour, but it will suffice to mention the facts that machining costs are avoided, waste of raw material avoided, and that the gear has a more accurate contour and better surface finish and is therefore more silent in operation. Iron parts of this type are manufactured much on the same lines used for the porous bronze bearings. Similar presses can be used, but the pressures are higher from 30 to 40 tons per sq. in. Sintering furnaces are similar, and the sintering temperature is in the region of 1,100° C. Furnaces fitted with roller hearths, or wire mesh conveyer-belts are employed. The sintering time is from 20 to 40 mins. in an atmosphere of dried partially combusted hydrocarbon gas. There is, generally, a slight shrinkage during sintering amounting to ½ to 3%. In most cases the pieces are sized after sintering, generally cold, but in some cases hot, at 400° to 500° C. Iron parts made in this manner have been produced experimentally with tensile strengths exceeding 50 tons per sq. in., but with the qualities of iron powder at present commercially available, and bearing in mind that wear on dies increases with pressing pressure, it is not customary to exceed a tensile strength of 9 to 15 tons. These parts can, therefore, be regarded as having very similar properties to the ordinary cast iron. As commercial experience is gained it will become possible to make use of the results of laboratory investigations where higher pressures and alloy-steel powders have been employed.

Hot Pressing

Finally, something must be said about hot pressing as a powder metallurgy technique. In this method of moulding powders, pressure is given to the powder while it is cold, and the cold compressed compact is heated up and then pressed again while it is hot. There are a variety of methods by which the method can be worked out, and similar techniques involve hot forging or hot extrusion. The method is not a difficult one, but so far has received little or no industrial attention. I have examined a wide variety of alloys prepared from powders by this technique, and find that it not only combines all the advantages usually associated with powder metallurgy, but in addition is capable of giving compacts having very excellent mechanical properties, and in some cases superior properties, to the cast article. These results have been published in detail, and it will be sufficient to state here that with an ordinary cast iron, tensile strengths of 36 tons per sq. in. have been obtained, and with bronzes, tensiles in excess of 23 tons per sq. in. combined with an elongation in excess of 75%. Similar results are obtainable with brasses and various other copper base and complex alloys.

Recently, an account has been published describing the application of hot pressing to the manufacture of steel parts from steel turnings. The process has been worked out in a very simple manner and appears to be highly successful. Starting with steel turnings valued at little over ½ cent per lb., a part is produced without machining, in six operations, which has approximately three times the strength of cast iron. The part concerned is a bearing lock sleeve used to hold the roller bearing in the differential carrier of the Chevrolet car. It is about 3 in. in diameter, $\frac{5}{8}$ in. thick, and a section thickness of $\frac{3}{8}$ in. One face is smooth at an angle of 20°, and the other with concentric recesses near the inner and outer edges. It weighs 8 oz., and hitherto was machined from grey cast iron.

The powder metallurgy method is as follows : Steel chips and turnings are fed into swing-hammer crushers which reduce them to a very coarse powder. They are then compacted in a hydraulic press under some 30 tons per sq. in. The parts are then treated in a pusher type sintering furnace fed with combusted gas. The furnace handles six parallel tracks of parts at a rate of 500 pieces per hour, giving each part approximately 15 mins. treatment at a maximum temperature of approximately 1,050° C. As the pieces drop from the sintering furnace they are quickly transferred by hand to the hot press. The dies used are of the hinged type and water cooled with a series of eight jaws applying pressure uniformly around the outer edge of the washer, while upper and lower dies compress the surface. Pieces are handled at the rate of 12 per min. in this press and are automatically removed from the dies and slide down a shute into a water-quenching bath. When cool the part goes to a trimming press and is then finally sized.

General Possibilities

Anyone who studies this process, and some of the others already described, cannot fail to be impressed with the fact that under favourable circumstances the technique of powder metallurgy permits either a saving in labour or a transference from skilled labour to semi-skilled labour, and also either a saving in raw material (by reducing losses) or a transference from virgin metals to the practical use of secondary metals. If this is appreciated, it will be realised that the processes of powder metallurgy are particularly suited to war-time production conditions. An extensive adoption of this technique would release considerable skilled labour and prevent the wastage of much raw material. While the possibilities of powder metallurgy are generally appreciated for the production of materials having special qualities, such as contacts, porous bronze, etc., it is only just beginning to be appreciated by engineers that the powder metallurgy industry is now at a stage where it has begun to manufacture articles that can be, and have been, manufactured by other methods, and that the powder metallurgy technique is now a preferred technique for the production of numerous machine parts characterised by excellent physical properties, accuracy of configuration, and substantial lack of porosity. In iron articles, tensile strength up to 25 tons per sq. in. present no difficulty in production, brasses and bronzes may be

(*Continued on page* 194)

Rationalisation in Iron Foundries

Part II. *(Contd.)*—Application of Principles

By F. L. Meyenberg, M.I.Mech.E.

In this section various aspects of time studies are continued. In the last issue the author considered the analysis of the work, and of the time involved in executing it. Further reference is made to analysis of time in the present section, and additions for lost time and for falling off in the rate of working are also considered. It must be emphasised that these are not secret methods, but are generally known ideas adapted to working conditions varying from one foundry to another.

IN the simple, but not rare, case when there is no intermediate time between the end of a process on one casting and the beginning of the same process on the next casting, the casting sequence time becomes identical with the piece time, i.e., the time between the beginning and the end of the process on one and the same casting, and Fig. 3 changes into the simpler Fig. 4.

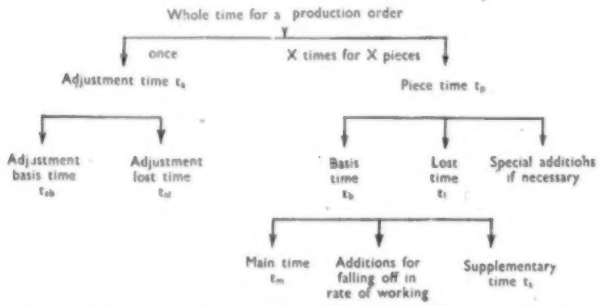


Fig. 4.—Allocation of the work in the foundry for a production order.

Sometimes it is necessary to allocate a time used for a special operation correctly to the kind of time to which it belongs. It may even be that this allocation depends on a custom in the foundry in question, or has to be decided upon according to the degree of organisation or division of labour in that foundry. Again, it may be useful to illustrate these explanations by examples from practice.

Allocation of work in the foundry to the various times characterised in Fig. 4. (These examples represent handmoulding practice. They are not instructions, but are given only to show how these questions have been answered in a special case in practice. The various times may be indicated as shown, i.e., basis time $= t_b$, adjustment time $= t_a$, lost time $= t_l$, etc.)

Thus, taking out the tools, t_l; receiving orders, t_{ab}; fetching patterns, t_{ab}; fetching facing sand, t_a; ordering cores, t_{ab}; providing for flasks and bottom board, t_{ab}; putting the pattern into the flask, t_m; discussing the work with the foreman, t_{ab}; complaint on wages in wages office. t_l; ordering bricking up material, t_{ab}; preparing sand for moulding, t_a; warming up the rammer, t_l; ramming the drag, t_m; waiting for crane, t_l; setting up the cope, t_m; fetching gaggers or grids, t_{ab}; relieving nature, t_l; general conversation with the foreman, t_l; ramming up the cope, t_m; fetching stands for the cope, t_{ab}; lifting off, turning and putting down cope, t_m; taking out pattern and finishing the mould, t_m; getting assistants for transporting the cores, t_l*; fetching cores, t_s*; fixing cores, t_m; closing the mould, t_m; fetching the runner box, t_{ab}; building up the runner basin, t_m; fetching weights or clamps for holding down cope, t_{ab}; applying weights or clamps to mould, t_m; collecting the tools, t_l; waiting for molten metal, t_l; pouring the metal, t_m*; feeding the casting, t_m*; taking off the weights, t_m*; cleaning the work-place, t_l; knocking out and wetting the sand, t_m*; transporting the castings to the cleaning and dressing room, t_m*; cleaning and dressing, t_m†.

The items with * are, in the case I, previously mentioned when discussing the various kinds of division of labour in foundries, the duty of special auxiliary workmen who are not connected with the moulding process proper. Similarly, the last item (with †) is carried out in the cases I to IV by a separate group of men.

It is possible that main times and supplementary times cannot be clearly separated from each other in a special case, then the basis time would be the last partition. Supplementary times can be divided in those which can be related directly to the castings to be produced, and in those where that is not possible. In the second case it is necessary for the purpose of wage fixing to find a key for indirectly allocating these times to the castings.

Of special importance in works generally, as well as in foundries, are additions to the times allocated, previous mention of which has been made, but which can now be discussed in detail. Two kinds of additions must be taken into consideration—that for lost time, and that for falling off in the rate of working. Both have often been forgotten, or intentionally excluded, when first carrying out systematic studies in industrial works. It is a bad mistake to overlook these two factors, and is one of the causes of the strong opposition to time studies experienced in some industrial groups. For this reason it is necessary that these two additions should be considered in detail.

Additions for Lost Time

The human body is very often likened to a machine. but this similarity can only be applied to a limited extent, In any case, if a human being, a complex combination of body, brain and spirit, is treated like a machine, the result is disastrous. It is impossible, for instance, for a man to work his shift with no interruption whatever. Of course nobody intends to advocate laziness, but care must be taken to satisfy the physical and psychological needs of the men in order that their work is done willingly and well. Sometimes their work must stop because of lack of organisation. This should not occur, but the human factor functions with managements too, and therefore imperfections or mistakes, e.g., lack of material, break of a belt, etc., cannot be entirely avoided.

Some allowance for the time lost by all these causes *must* be made and the only question is, in which manner and to what extent.

It is usual to make a percentage addition to the bases times, the adjustment basis time as well as the basis time proper. The percentage can be the same in both cases, e.g., 8%, or it can be different, e.g., 10% in the first, 7% in the second case. That depends entirely on the special working conditions, and cannot be decided without further investigation.

This opportunity may be taken to point out the importance of separating adjustment time and piece time. Figs. 3 and 4 indicate this separation; the first occurs in each batch only once, while the second has to be accounted for as many times as there are castings in a batch. Many difficulties are encountered from the fact that this difference in principle has not been adequately considered, resulting

in incorrect planning, or in the notorious "good" and "bad" piece-work prices.

When the character of additions for lost times has been clearly recognised in principle it is necessary to determine the percentage itself, and this is possible only from case to case, or at least for a certain workshop or function. When observing a special shop it will soon become evident that certain customs, developed in the shop, have established a character that is not easily changed without endangering the result of the work. These customs have a great influence on the percentage additions for lost time, and it would be a mistake to fix this percentage, even by arrangement between employers and employees' organisations, in order to avoid the work involved by a special investigation to determine the percentage advisable in the case on hand.

There is, however, another reason why this special investigation should not be omitted. Experience has shown that almost nothing is so suited for providing a clear view into the peculiarities, merits as well as drawbacks, of the shop in question as a determination of the lost times.

In order to show what is actually understood by lost-time studies it is of interest to give the result of such an investigation taken for a whole workday of a man beginning at 7 a.m. and ending at 5-15 p.m.—i.e., 10 hours 15 mins., or less 1 hour + 15 mins. for meals, 9 hours = 540 mins. The lost times were :—

(*a*)	Assembling the tools		8 minutes	
	Waiting for crane	2 + 3 + 5 + 4 =	14 ,,	
	Relieving nature	3 + 9 =	12 ,,	
	Discussion with foreman	2 + 1 + 3 =	6 ,,	
	Journey to the time office		5 ,,	
	Fetching assistant		3 ,,	
	Waiting for molten metal		7 ,,	
	Cleaning work-place		6 ,,	
				61 minutes
(*b*)	Arriving late		4 minutes	
	Conversation with colleagues		5 ,,	
	Leaving early		2 ,,	
				11 ,,
(*c*)	Patching cores			16 ,,
	Total			88 minutes

The lost times in the example are divided into three groups, (*a*), (*b*) and (*c*), according to their different nature. Those in group (*a*) are unavoidable, at least under present working conditions. Of course an endeavour should be made to limit them to a minimum; it must, however, be clear to everybody—and should be pointed out to the men—that nobody can expect them to disappear completely. Therefore, corresponding additions must be made in all circumstances to times resulting from time studies or other methods—i.e., to actual working times for a special job. Those in group (*b*) should not occur, but their avoidance is completely in the power of the men, and additions should not be made for these times. Those in group (*c*) involve doubtful decisions, and perhaps in the present case the work in question may be completely outside the job under investigation and should, therefore, be left out from further consideration. The actual working time in this case is $540 - (61 + 11 + 16) = 540 - 88 = 452$ mins., and the percentage addition $\frac{61}{452} \times 100 = 13{\cdot}5\%$.

The procedure of this study is comparatively simple, the times to be determined long enough, and the accuracy needed for the observation small enough, to use a normal watch with hands for minutes and seconds, but as lost times, according to their nature, take place quite irregularly, it is necessary to extend these lost-time studies over a long time, say at least a week, if a correct impression of conditions in the shop or foundry is to be obtained.

In contrast to these lost-time studies those of main and supplementary times can be shorter, but must be the more accurate, the more jobbing work develops into series- and mass-production practice. In these cases the usual watch rapidly becomes unsuitable, and a stop-watch must be used. It has been found that the division of the minute into 10ths and 100ths is more convenient than the normal division into 60 secs., as it greatly facilitates the evalution of the figures written down during the studies; it is therefore recommended that stop-watches with this decima division should be used.

In some cases, especially with machine moulding, it is possible to use recording instruments, some actuated by the observer, some being automatic and continuous, and actuated by parts of the mechanism that is under observation—e.g., the moulding machine. Although the prime costs of these instruments are high they can be recommended because, in the first case, the observer can give his attention completely to watching the work, or in the second case of the automatic instruments the costs of use are small, and some workmen prefer to be controlled by an instrument rather than by an observer.

A greater refinement of these studies is obtained by means of a film camera. This can be recommended only in rare cases, especially if motion units are being investigated on a large mass-production basis, or if slow-motion pictures are needed for training purposes, etc. Generally, however, the normal watch and the stop-watch and, in certain infrequent cases, recording instruments are sufficient; this fact has been emphasised, as the more-refined methods are sometimes used, from the initial stages, on unsuitable objects, or before more simple means have been used to correct mistakes with the possible tendency to discredit the whole idea of time studies.

Returning from this deviation on the instruments used when carrying out time studies to the additions for lost time, it may be emphasised again that however much it may be the endeavour of all concerned to shorten the lost time, it must be understood clearly that it is not possible to eliminate lost time completely, and some addition to the time actually found by time studies is therefore necessary in all circumstances. By neglecting this fact the men are treated unfairly, and trouble is unavoidable.

Additions for Falling Off in the Rate of Working

These additions are also necessary, and result from the fact that the work is not carried out by automatons but by human beings, from whom an uninterrupted and equal output, hour after hour, during a whole shift cannot be expected. This applies especially to work in foundries, which, to some extent, results in a weariness which increases the further the shift progresses, and can finally only be overcome by an adequate time of rest. Thus, for instance, it could be observed on a moulding machine that, after elimination of lost and supplementary times, the output fluctuated as follows, taking the number of finished flasks as a measure :—

1st hour	15 flasks	5th hour	12 flasks
2nd ,,	12·5 ,,	6th ,,	14 ,,
3rd ,,	14 ,,	7th ,,	12 ,,
4th ,,	13 ,,	8th ,,	11 ,,

The average output was 12·9 against a maximum of 15.

This confirmed the fact, known from scientific observations, that the efficiency of a man is highest during the first two hours of work and then falls off, recovering somewhat after short rest times inserted in the working time, but recovery is short and falling off quickens afterwards. That this process takes a somewhat irregular course is not only due to the fact that a human being is not an automaton, but also that some minor troubles are included in these observations of weariness, or fatigue, which cannot be taken into account by lost time—or supplementary time—studies. They are, nevertheless, unavoidable in practice, partly because the man becomes tired and partly from other reasons. The science of physiology and psychology has, in spite of the great progress made in recent times, not sufficiently advanced to give full explanations and exact laws governing these phenomena. Thus, falling off in the rate of working must be accepted as a fact and a figure determined, and based on simple considerations and experience that has been proved true for practical purposes. That has been the case with the data given below. At first these data could only be said to apply for the working conditions investigated, but actually it was found that they were sufficiently accurate for application to all foundries

in which conditions did not vary too much from those in general operation.

It is clear that the degree of falling off in the rate of working must be related to the amount of work itself. This work can be expressed generally by the product of the force and the distance along which the force has to be exercised in the unit of time. Generally, the distance can be disregarded as any differences are relatively small, e.g., in machine moulding the distance the moulder has to carry the flasks filled with sand vary little in well-organised shops. Thus, the output in weight can be used as measure of the work. It is obvious that the additions in question are necessary only for that part of the work which causes the moulder fatigue, e.g., with machine moulding work—(1) setting up the flask (weight of the flask), (2) shovelling in sand (weight of the sand), (3) ramming, (4) taking off and putting aside the flask (weight flask and sand).

For reasons of simplification the ramming of the sand has also been measured by the output in weight, i.e., 17·5 lb. 1 cu.-ft. sand for the usual height of sand to be rammed in machine moulding, say, up to 10 in., and 20·5 lb. 1 cu.-ft. for larger heights; the second figure (20·5) can be used also for core-making. The reason for this higher figure is that in making cores, as well as when ramming unusually high flasks, the core or mould may require a greater density of sand. By means of these figures a common addition can be determined for the before-mentioned four motions, and the final result is given in the following table, which has proved sufficiently correct in practice. It should be noted that the addition for falling off in rate of working is related to what has been termed main time. Thus, when using this table it is necessary to know (1) the output in pounds, i.e., 2 × (weight of flask + sand) + (2·75 or 3·25) × cu.-ft. of sand, and (2) the main time. If, for example, (1) equals 320 lb. in a main time of 3·6 min., i.e., $\frac{320 \times 60}{3 \cdot 6} = 5{,}300$ lb. per hour, the addition for falling off in the rate of working is 23%, or 0·23 × 3·6 = 0·8 mins.

Output in lb. hr.	% Addition.	Output in lb. hr.	% Addition.	Output in lb./hr.	% Addition.	Output in lb./hr.	% Addition.
220	7·5	1,540	17	8,500	27	15,800	37
260	8	1,940	18	9,200	28	16,500	38
310	9	2,600	19	9,900	29	17,200	39
350	10	3,300	20	10,600	30	18,200	40
440	11	4,000	21	11,400	31	18,700	41
550	12	4,800	22	12,100	32	19,500	42
660	13	5,500	23	12,800	33	20,200	43
810	14	6,200	24	13,600	34	20,900	44
990	15	7,000	25	14,300	35	21,700	45
1,230	16	7,700	26	15,000	36	22,500	46

There is no question that the work outside the main time is also fatiguing to the workman, but as other groups of muscles of the human body are strained during the supplementary time, etc., a simple addition can scarcely be justified; in any case, the described method has been found practicable.

It is not difficult to work out tables, graphs, etc., to facilitate the calculation of the figures needed in a special case and to determine the correct addition; the actual work, therefore, becomes a routine use of these expedients and takes only a very short time. It is not proposed to describe this aspect in detail, since it would tend to lead away from the main object of this report. It may, however, be mentioned that the standardisation of flasks, tools and work-places—so useful from other points of view—greatly decreases this work of evaluation of time study results, as figures obtained during a special investigation are useful to settle this question.

It may happen, in some cases, that this method of calculating the addition for the falling off in the rate of working gives no reasonable result. It may be that the work in question is of such a nature that fatigue does not arise; or the working time, in the case in question, is so long and the actual moulding process so complicated that the falling off in the rate of working is not only due to fatigue, but to a decrease in the mental capacity of concentration. The former instance is so rare in foundries that practically it can be dismissed altogether. In the second instance, however, figures have been developed from experimental results in hand-moulding and core-making shops showing the direct percentage additions to the main times, neglecting the weight of the flasks, rammed sand, etc. It must be left to the responsible man which of the two methods he would like to apply in a special case, but it must be stated that the first is obviously more accurate and should be used wherever the nature of the work permits.

Main Time in Mins.	Addition in %.	Main time in Mins.	Addition in %.	Main Time in Mins.	Addition in %.
20	12½	200	6½	540	3
40	9	240	6	660	2
80	8	280	5½	780	1½
120	7½	320	5	900	1½
160	7	420	4	1,140	1

Special Additions if Necessary

It has been pointed out in Figs. 3 and 4 that other special additions should be made. The main reasons of these special additions are rejects, exceptionally small number of castings for one order and excess of work in consequence of unexpected trouble, defects of patterns, etc. If it is customary that rejects, even if not caused by bad workmanship, are not paid for, an addition to the time determined by time studies must be made. The amount may be fixed by agreement between management and workmen, or their organisations, and based on statistics carried out for this purpose.

The addition for an exceptionally small number of work-pieces for one order is necessary, especially in a machine-moulding shop. It is well known that a man always needs some time for making himself acquainted with a new job before the correct rhythm of work appears as that resulting from series- or mass-production. If the time study has been made under series- or mass-production conditions, and then later the same work must be repeated for a small number of castings, say below 25, it is obvious that a longer time must be allowed for the job. This addition depends on the number of work-pieces actually produced, on the length of the piece time, and on the difficulty of the work.

To meet requirements for this allowance in a machine-moulding shop, it has been proved useful to form the required number of castings into three groups—1 to 3, 4 to 10, and 10 to 25—and to divide the degree of work into three groups also, viz., easy, normal and difficult. These provide nine groups, for which corresponding additions in per cent. can be determined for basis times of 3, 5, 10 and 15 mins. The actual figures are omitted as these additions are only concerned with exceptional cases.

The additional working time caused by sudden and unexpected troubles, defects, or mistakes of patterns, etc., is perhaps one of the most interesting items to the time-study engineer. These seemingly unimportant details, coming to light during his investigations, or as a consequence of the piece rates based on his studies, give valuable hints where improvements of design, production or organisation are possible, and they should, therefore, be recorded carefully, and all reasonable conclusions drawn, as completely and as quickly as possible. As to the payment of the men for this time, it is certainly best to keep it separately and not to include it with any piece rate—i.e., it should not be treated as an addition to the piece time of the job during which it occurs.

(To be continued.)

The Behaviour of S.82 about its Critical Range, and the Application of this to Annealing Practice

By C. Wilshaw

The fact that nickel-chrome steels, when heated at gradual rising temperatures and cooled in water, show progressive hardening at temperatures considerable below the beginning of AC_1 is known, but the author draws attention to some interesting experiments which are concerned with annealing to facilitate machining. Treatment is recommended which has for its object a reduced time cycle and saving in furnace hours.

AT the outset, it may be helpful to describe briefly the changes which occur in the structural condition of a plain carbon steel when it is heated through the temperature range with which we are concerned in this paper, namely, 600° C. to 800° C. With such a steel heating within this range, but below the lower critical point (AC_1), would result in spheroidisation of the cementite to a degree dependent on the proximity of the temperature employed to the AC_1 point (730° C./750° C.), and on the previous condition of the material. Setting aside the latter point, and dealing with samples in the hardened and tempered state, heating from 600° C. to 720° C. produces progressive coalescence of the carbide particles. Soaking for some time at a temperature just below the critical point ultimately results, particularly with mild steel, in the carbide agglomerating in comparatively massive form at the grain boundaries. Alongside this process a certain amount of the carbide is taken into solution, due to the increased solubility of carbide in alpha-iron at this temperature. When a spheroidised steel is heated to a temperature just above the AC_1 point, the carbide particles go into solution and produce a number of austenitic areas containing the eutectoid percentage of carbon. The amount of austenite produced will thus depend upon the carbon content of the steel: if, for instance, the sample is in the carburised condition the amount of austenite will increase to totality in passing from core to case. With a hypoeutectoid steel the structure will now consist of ferrite and austenite. When the temperature is raised still further, however, the ferrite begins to be absorbed by the austenite, and this absorption is completed as the steel emerges from the upper end of its critical range. The carbon content of this austenite will then correspond to the carbon content of the steel. On cooling the austenite will, of course, be transformed into pearlite or martensite, depending upon the speed of cooling, but these changes do not concern us here. The point which it is wished to emphasise in the foregoing is that the transition from the unhardened to the hardenable state occurs quite abruptly.

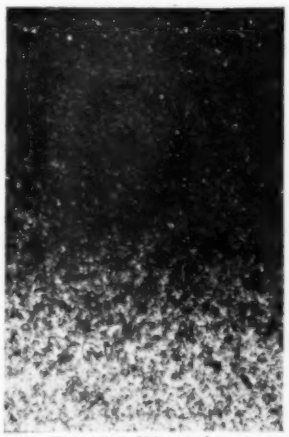


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Fig. 1.—Case, oil quenched at 640° C. x 94.

We shall now see how the behaviour of nickel-chrome steel compares and contrasts with this, and the relation which this behaviour has to heat-treatment practice.

The experimental work, on which the following results are based, was conducted, as previously stated, with S.82 material in the carburised condition. The core analysis was as follows: 0·21% C; 0·45% Mn; 4·00% Ni; 1·17% Cr; trace Mo; no V. After carburising, the $1\frac{3}{16}$-in. diameter bar was cut into discs $\frac{1}{2}$ in. thick, and these were then all refined in the usual way by soaking at 840° C. and oil-quenching. The following treatments were then given and case- and core-hardness readings obtained in each instance:—

	Case, Rockwell C.		Core, 50 kilo VPN.
Heated to 600° C., soaked 30 mins., oil-quenched	36	..	276
,, 620° C. ,, 30 mins. ,, ...	36	..	276
,, 640° C. ,, 30 mins. ,, ...	35	..	263
,, 660° C. ,, 30 mins. ,, ...	37	..	266
,, 680° C. ,, 30 mins. ,, ...	44	..	294
,, 700° C. ,, 30 mins. ,, ...	49	..	339
,, 720° C. ,, 30 mins. ,, ...	55	..	359
,, 730° C. ,, 30 mins. ,, ...	58	..	385
,, 740° C. ,, 30 mins. ,, ...	63	..	396
,, 750° C. ,, 15 mins. ,, ...	63½	..	450
,, 800° C. ,, 10 mins. ,, ...	61	..	460
*Ditto, but cooled in furnace from 800° to 700° C., soaked 10 mins., and then quenched	62	..	458

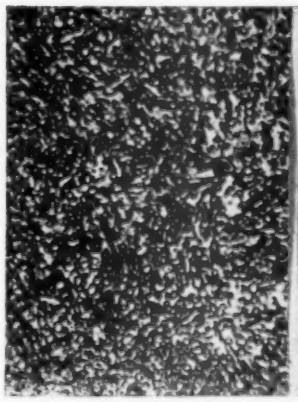

Fig. 2.—Case, oil quenched at 640° C. x 1,500.

Fig. 3.—Core, oil quenched at 640° C. x 1,500.

To verify certain of these results, and the structural changes observed, additional specimens were soaked for a considerable time as shown and hardness readings again obtained:—

	Case, Rockwell C.		Core, 50 kilo V PN
Heated to 640° C., soaked 18 hours, oil quenched....	31	..	224
,, 675° C. ,, 18 hours ,, ...	35	..	266
,, 693° C. ,, 18 hours ,, ...	45	..	310
,, 710° C. ,, 18 hours ,, ...	60	..	324

The most noteworthy feature of these results is, of course, the gradual increment of hardness in the samples heat-treated above 640° C. It is convenient to consider first, however, the significance of the figures marked thus.* This specimen showed, on micro-examination, precisely the same structural condition as the specimen quenched outright from 800° C.; that is, the furnace cooling and the short soak at 700° C. had been quite ineffective in preventing full hardening of case or core. This, of course, is quite understandable with this class of material since the critical

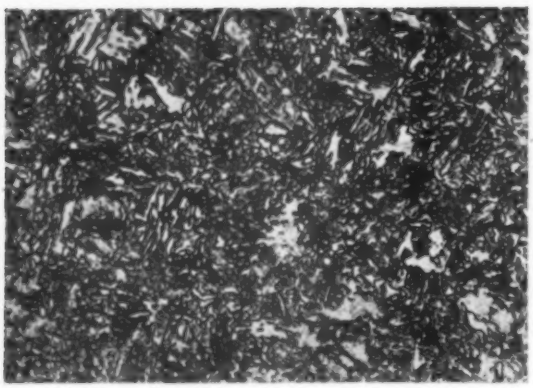

Fig. 4.—Core, oil quenched at 700° C. x 625.

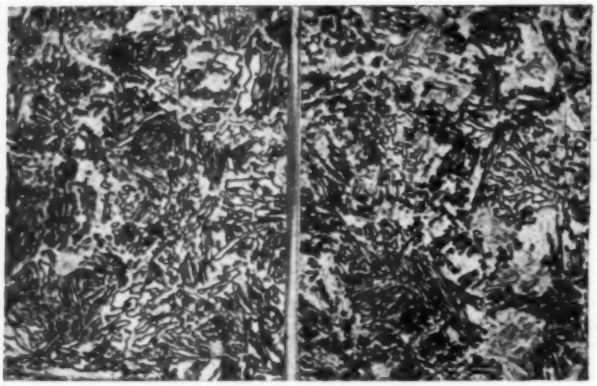

Fig. 5.—Core, oil quenched at 730° C. x 625.

Fig. 6.—Core, oil quenched at 740° C. x 625.

rate of cooling required to produce a depression of the critical range is very low. The significance of this in practical heat-treatment is not, however, always appreciated. For instance, if during the soak at hardening temperature the specified quenching temperature is exceeded either by inefficient control, or by the work being placed in a furnace cooling from refining temperature, the physical properties of the core, as regards hardness and impact values, will be equivalent to those which would have been obtained had the work been quenched from the highest temperature which it had reached, irrespective of whether the actual quenching temperature had returned to normal. Another point is that softness of case or core is hardly likely to be caused by delay in transferring work from the furnace to the quenching tank. Assuming that correct soaking has been given at the hardening temperature, such softness will be found to be due to tempering effects the result of bad manipulation in the quenching bath.

Returning to the condition of the material in the annealing range of temperature, it will be noted that the hardness figures quoted are for specimens in the oil-quenched condition. This was done for the sake of consistency, but it has been ascertained that although the quenched specimens give a steeper curve the same tendency is shown by samples in the air-cooled condition.

Samples treated at 640° C. show the case condition illustrated in Fig. 1. At a higher magnification this is found to consist of fine spheroids of carbide in an acicular or dappled matrix (Fig. 2). The core condition shows little, if any, ferrite separation even after 18 hours (Fig. 3). The structure consists, for the main part, of extremely fine particles precipitated along the crystal planes in a light etching even-toned matrix. This condition is produced at about this temperature irrespective of whether the core was previously in a fully hardened or partially ferritic condition.

On raising the temperature above 640° C. the core shows the separation of an increasing amount of ferrite. The progress of this separation is shown in Fig. 4 (700° C.). Between this temperature and 720° C. the ferrite separation reaches a maximum, and as the temperature is increased still further ferrite is absorbed in the normal way. Figs. 5 and 6 show the decreasing amount, and at 760° C. the solution will be homogeneous and capable of full hardening.

The changes in the case in the same temperature range are as follows. Raising the temperature above 640° C. produces a progressive *solution* of carbide particles. At first the particle size of the carbide remaining out of solution tends to increase very slightly, and at 680° C. we have the structure shown in Fig. 7—carbide spheroids in acicular matrix. At 720° C. only extremely fine particles of carbide remain, the matrix now being definitely acicular (Fig. 8). The changes in the general appearance of the case are shown in Figs. 1, 9 and 10. After quenching from 730° C. we find the presence, for the first time, of a fully hardened zone in the case—i.e., a zone containing neither excess carbide nor free ferrite. This zone lies towards the inner side of the case (Fig. 11). Increase in temperature brings about an increase in width of this zone (Fig. 12) until the structure, at 760° C. to 800° C., becomes that which we are accustomed to seeing in hardened S. 82 cases (Fig. 13).

Prolonged soaking causes the appearance of a fully hardened zone in the case at a rather lower temperature, 710° C. (Fig. 14).

Perhaps the first explanation which offers itself, of the steady increase in hardness which accompanies, in the core, the separation and then the solution of ferrite, and, in the case, the progressive solution of carbide, is that it is

Fig. 7.—Case, oil quenched at 680° C. x 1,500.

Fig. 8.—Case, oil quenched at 720° C. x 1,500.

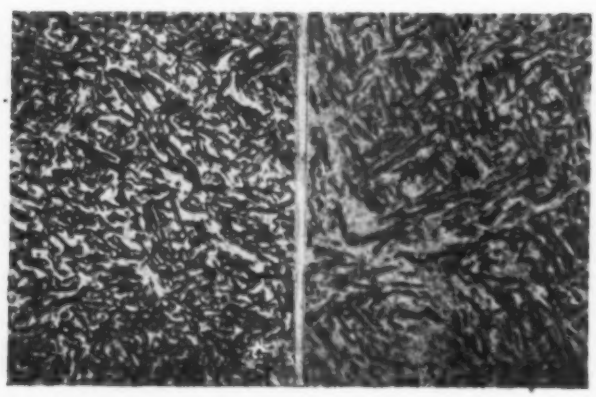

Fig. 9.—Case, oil quenched at 680° C. x 94.

Fig. 10.—Case, oil quenched at 720° C. x 94.

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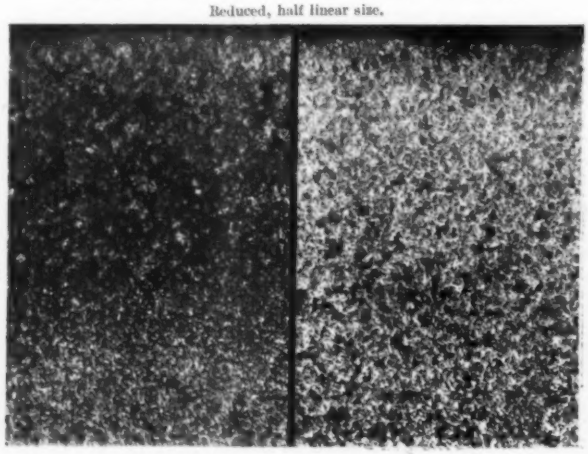

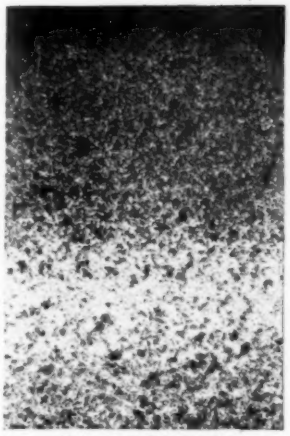

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Fig. 11.—Case, oil quenched at 730° C. x 94.

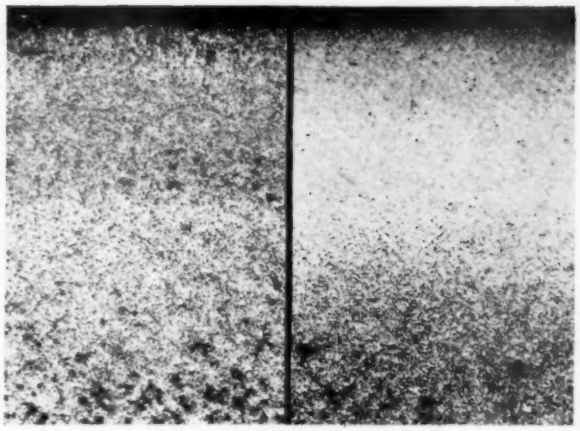

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Fig. 12.—Case, oil quenched at 740° C. x 94.

Fig. 13.—Case, oil quenched at 800° C. x 94.

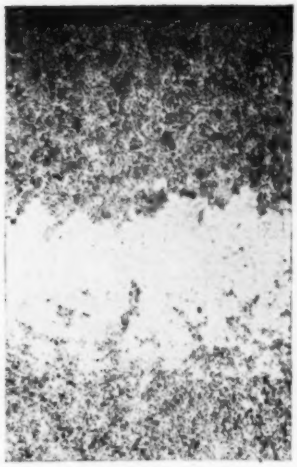

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Fig. 14.—Case, oil quenched at 710° C., after prolonged soaking. x 150.

produced at first by precipitation hardening, caused by the increased solubility of carbide in alpha-iron just below the critical range. This explanation will not, however, be found satisfactory. If it were true the increasing hardness of the core in this temperature range would be due entirely to the increase in amount of supersaturated ferrite or alpha-iron, and this might well be so if it were not for the changes we find, over the same temperature range, in the case. Fig. 14 or 11 shows the existence of a definitely martensitic zone between case and core, and examination at a high magnification (Fig. 15) of this region of the specimen shows that the same constituent constitutes the matrix of the core around the ferrite particles. It is, therefore, obvious that it is the presence of this constituent in the core which brings about the increase in hardness.

Considering the separation of ferrite in the core side by side with the absorption of carbide in the case, in the temperature range of 640° C. to 720° C., we are drawn inescapably to the conclusion that the A_1 changes which normally occur at a definite temperature are here occurring over a range. Thus, in the core, the increasing separation of ferrite, when considered alongside the changes taking place in the case, must be ascribed to the increasing solubility of the carbide, causing the increasing concentration of the resulting solid solution, which gives in turn increased hardening power on cooling. From 720° C. to 760° C. the increased hardenability is, of course, due to normal causes—the normal elimination of the soft constituent, namely, ferrite. The changes which occur in the case are, of course, parallel to those in the core. Increase in temperature produces progressive increases in carbide solubility and hardening power. This results shortly in the appearance of the homogeneous and presumably eutectoid band which has been seen in the microphotographs, followed by the widening of this zone with further increase in temperature.

Summarising, instead of the gradual coalescence of the carbide, accompanied by progressive softening, and then an abrupt increase in carbide solubility and consequent hardenability, which is obtained when a plain carbon steel is heated up to the AC_1 point; with this nickel-chrome steel only a very limited amount of coalescence occurs, and the increase in carbide solubility and consequent hardenability develops gradually with increase in temperature, and *not* suddenly at one particular temperature.

With S.90 (5% Ni) material there is a similar tendency for hardness increments below the critical range, and for these to be associated with ferrite separation in the core. The structural changes in this region are, however, less distinct than with the nickel-chrome material, and the transition in the case to the fully hardened condition occurs much more abruptly, as will be seen from Figs. 16 and 17. Only 10° C. separated the quenching temperature of the specimens illustrated here.

Whatever the theoretical explanation of the behaviour of nickel-chrome steel on heating above 640° C., its practical importance cannot be ignored, particularly its relation to annealing practice. The futility of annealing at 700° C, as has been suggested, will readily be seen.

Nickel-chrome steel is probably the most difficult alloy steel to anneal successfully, and this difficulty is encountered

Fig. 15.—Region between case and core. x 406.

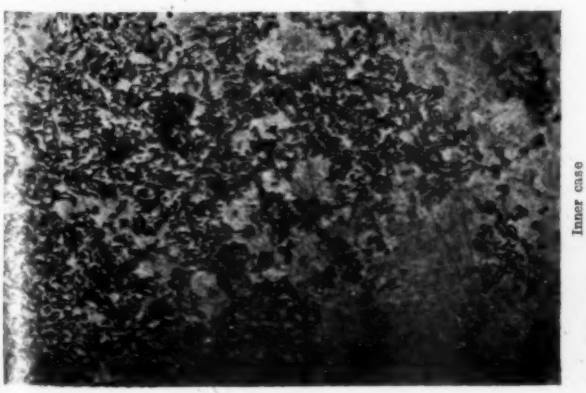
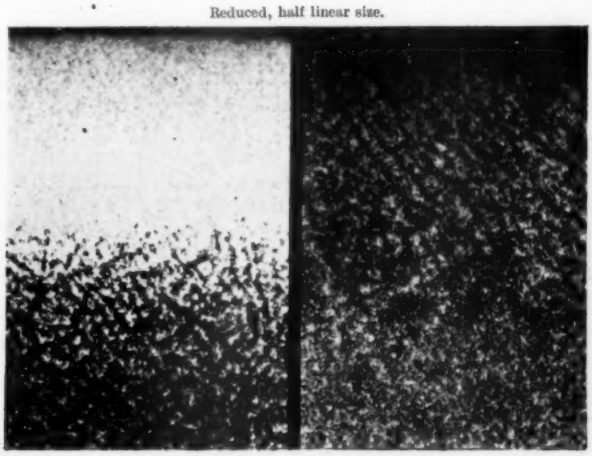


Fig. 16.—Transition in the case of S.90 when oil quenched at 700° C. x 94.

Fig. 17.—Transition in the case of S.90 when oil quenched at 690° C. x 94.

Reduced, half linear size.



particularly in preparing components in S.82 material for machining after carburising. The processes most generally employed are box annealing, or double open-hearth annealing at 650° C. Either process gives satisfactory results as a rule, but the time cycle is long, usually from 20/30 hours, and most of this time is furnace hours.

This difficulty in obtaining adequate softening is undoubtedly due to the extreme sluggishness with which the carbide precipitates and, in particular, coalesces. It was noticed when examining the cases of the experimental samples that for any one temperature little, if any, difference in the size of the carbide particles was obtained from a ½-hour soak and an 18-hour soak. There is, therefore, no justification for prolonged soaks at annealing temperatures with this material. It is the writer's opinion, too, that undue emphasis is placed on the rate of cooling from process annealing temperatures, since he has found that, provided the following procedure is adopted, air-cooling suffices. This procedure consists of a soak for 2 hours at 680° C., followed by air cooling, then a further 2 hours soak at 640° C., and again air cooling. After this treatment carburised components give a Rockwell hardness of C.28/C.32, and machine satisfactorily. The writer bases this treatment on a consideration of the observed results when S.82 material was heated to various temperatures as described earlier. At 680° C. there has been some carbide solution in the case, but no diminution in the size of the remaining particles. On the other hand, because of the carbide solution, the matrix hardens slightly on cooling, as has been shown earlier. If the material be now heated to 640° C., the temperature of maximum carbide separation, that amount of carbide which was taken into solution at 680° C. will now be reprecipitated, and the tendency will surely be for this carbide to precipitate preferentially on the nuclei of the particles already out of solution. The result will be to obtain softening of the matrix, and a greater degree of carbide coalescence, in a considerably shorter time than the more orthodox methods.

On a production scale this method is worked most efficiently by employing a charging machine and two or three cooling tables in conjunction with two furnaces. The volume of work would, of course, have to warrant this; but there is no objection to including material of S.90 specification to make up the charges. The S.90 substitute, En 36, also benefits from this treatment. One of the furnaces runs continuously at 680° C., the other at 640° C. A load of work for annealing is introduced into the 680° C. furnace, and when the charge has attained temperature it is given the 2 hours soak. The load is then withdrawn and cooled off to some 200° C., and is then introduced into the other furnace for the 2-hour soak at 640° C. The charge is then withdrawn and allowed to cool to handling temperature, when it is ready to go out for machining. The process is continuous—that is, when one charge is withdrawn from a furnace another should be ready to introduce. In this way advantage is taken of the sensible heat of the furnace in heating the cold charge, instead of allowing it to dissipate as is done when the charge is cooled with the furnace. Because of the quicker heating of the charge, therefore, and its removal from the furnace for cooling, the furnace hours for the annealing cycle are reduced to 8—10 hours, depending on the size of the charge. It is, of course, this saving in *furnace* hours which heat-treatment plants will most appreciate at the present time. This process has been in operation at the writer's works for some time now, and consistently satisfactory results have been obtained with regard to machining. One precaution, however, is worth observing where very heavy loads are charged—to place the S.82 material, which is more sensitive to temperature, so that it lies in the central region of the furnace.

Where the handling equipment, or the volume of work, does not make the above method practicable, it should be possible to adapt the normal double annealing process where this is employed, i.e., instead of two annealing periods at, say, 650° C., use the temperatures of 680° C. and 640° C., and cut down the soaking time to 2 hours at each temperature. The charge will, of course, have to be cooled down with the furnace to about 250° C. between the two soaks, but this can be expedited by opening the furnace-door slightly.

Finally, it should be emphasised that, unlike some other annealing methods, the hardness readings obtained give a reliable indication of whether the annealing has been a success. As already stated, the hardness obtained should not be in excess of C.32 with S.82 material in the carburised state, and C.28 with S.90 in the same condition.

Powder Metallurgy: Its Products and Their Applications

(*Continued from page* 187.)

obtained with tensiles between 15 and 25 tons per sq. in. accompanied by elongations between 20 and 75%. Little work has been done on aluminium alloys, but physical properties similar to castings have been obtained. These results in the broad field of small non-porous precision machine parts are accompanied by the advantages of rapid production (300 parts per min. from one press) high dimensional accuracy (tolerances of ± 0·001 in. on 2 in.) and little or no scrap loss. In America production of such articles is being undertaken in various metals to a considerable extent, and may develop into an industry rivalling that of the plastics. Production work of this kind is not yet being undertaken in this country, although there are a number of firms investigating the position. As an example of the possibilities of powder metallurgy, the following represent a list of articles which are, or could be, made from powders, in the field of marine engineering. This is not an exhaustive list, but represents a few items which come to the mind as being typical examples:—

Piston rings, either in special alloys or not, for feed pumps, Diesel engines, and reciprocating steam engines. Also packing rings and the like.

Valves and seatings, such as for feed pumps, safety valves, steam traps, etc.

Turbine blades.

Bushings and bearings for light auxiliary machinery, small cams, tappets and pinions.

The electrical field embraces many possibilities, such as commutator segments, brushes, contacts, etc., but the largest field is possibly in the manufacture of instruments where numerous small parts are required, like cams, tappets, screws, bearings, magnets, etc. The radio and telephone trades already employ considerable amounts of powders in the manufacture of cores and transformers.

Strength properties of chromium-manganese-molybdenum refined steels *

Cr–Mn–Mo steels containing Mn 1 and Cr 3, or Mn 1·4–1·8 and Cr 2% along with small quantities of Mo and V were tested for their structure, hardness, yield point, tensile strength, elongation, compression, notch impact, annealing brittleness and torsion limit. The specimens were 40–140 mm. in diameter. The results showed that a Mn content in excess of 1% offers no advantage in alloys to be used for machine construction. For machine parts, such as crankshafts and airplane parts, Cr–Mo and Cr–V steels containing the usual atmospheres of Mn are more suitable to replace Cr–Ni–Mo–V steels than are Cr–Mn steels. Up to 1% of Mn is permissible in the steels in order to improve their hardening properties. Cr–Mn steels containing Mo or V are suitable for parts having large dimensions. The results are tabulated and presented graphically.

* Heinrich Cornelius and Helmut Krainer. *Stahl u. Eisen* 61, 871-7 (1941).

Magnesium and its Production

By the careful compounding of suitable alloys and the adoption of special technique in fabrication, magnesium-base materials possess mechanical properties which have gained for them an important place among structural materials. The demand for them is so great that expansion of the magnesium metal industry has been proceeding at a phenomenal rate. This survey of raw materials used and processes employed is mainly extracted from the Peter Le Neve Foster Lecture recently delivered by Dr. C. H. Desch before the Royal Society of Arts.

FIRST isolated as a metallic element very early in the nineteenth century, magnesium was not used industrially until 1909, and then only to a very small extent. The delay in its application was not due to the scarcity of its minerals, because magnesium is present in abundance in the earth's crust, but rather to the delay in the development of methods for the extraction of the metal. Magnesium is a chemically active metal, which unites readily with other elements and a great expenditure of energy is necessary to set it free. It is only during comparatively recent years that the vacuum technique for the reduction of the oxide was developed on a large scale, and the electrolytic method applied in the chloride process.

Like most pure metals, magnesium is soft, and has low mechanical properties, and only after continuous research with alloying elements to improve its strength characteristics has it been possible to take advantage of its very low specific gravity in structural work. Very great progress, however, has been made in recent years, and as a result of research many magnesium-base alloys have been developed which have been in regular production for some years. Originally applied to the production of castings, more recent developments have been the production and application of sheet, forgings and extrusions.

Magnesium-base alloys have characteristics which make them distinctive among metals; they are the lightest industrial alloys, being about two-thirds the weight of aluminium and about one-fourth that of iron and steel. They possess excellent machinability, toughness, and fatigue endurance, and on a strength/weight ratio they possess a strength equal or superior to most other metals.

In view of these characteristics, which have been developed by careful compounding of alloys and by the adoption of special technique, it is not surprising that this metal has been in great demand since the beginning of the war, particularly in connection with aircraft production, with the result that the magnesium metal industry is expanding at a phenominal rate; the United States, for instance, planned for an annual production rate of 265,000 tons by the end of 1942, and plans are in operation to augment this rate of production during the present year.

The increasing demand has led to concentration on the development of new processes, whereby raw materials that formerly seemed of little or no value have suddenly assumed prime importance, and the masterly survey of the raw materials and processes employed in the production of magnesium by Dr. C. H. Desch, in the Peter Le Neve Foster Lecture he delivered recently before the Royal Society of Arts, is timely. In view of the importance of ample supplies of this metal in these times, the following extracts from this lecture will be both interesting and informative, but readers who are specially interested should read the complete lecture :—

Magnesium Minerals

Pure magnesium minerals are only of local occurrence. The carbonate, magnesite, is found in its purest form in Austria, Greece, and California, but Canada, the States of Washington and Nevada, the U.S.S.R., and Manchuria, have very large deposits of less purity. The double carbonate of magnesium and calcium, dolomite, is far more widely distributed, and there is an abundance of it in this country. The chloride in the form of the double salt with potassium, carnallite, occurs in large quantities in the Stassfort deposits of Germany, and other salts of less importance have a local distribution. Sea-water provides an inexhaustible source of the chloride in an exceedingly dilute form, and certain concentrated brines occur in the United States, whilst the Dead Sea has also been suggested as providing a relatively concentrated solution of magnesium salts. Brucite, the hydroxide, is mined in Nevada.

Magnesia has important uses besides being the source of metallic magnesium. It is one of the essential refractory materials in the metallurgical industries, and magnesium oxychloride cements also consume considerable quantities. The purer varieties find application in the manufacture of magnesium salts, which are used in many industries. The greater part of the production is by calcining magnesite, which is carried out in either shaft or rotary kilns. When the calcination is carried out at about 850° C. the product, which still retains a little carbon dioxide, is porous and reactive, and readily absorbs moisture. Calcined at 1,500° C. or higher it is converted to crystalline periclase, and is described as dead-burned. It is then much less reactive. The temperature at which dead-burning sets in is lowered by the presence of iron, which is the most usual impurity.

A high degree of purity being required when magnesite is used as the raw material for the preparation of the metal, the choice of deposits has been somewhat limited, and it has been necessary to import the mineral in most instances. To save transport, it is sometimes calcined before being exported, but the process must then be carried as far as dead-burning, as the lightly calcined material absorbs moisture and carbon dioxide and becomes friable. Experiments have been made, however, in the concentration of magnesite of lower grade, and such procedure may make available sources which have hitherto been considered less satisfactory. The Nevada deposit has been successfully concentrated by flotation, and there are records of other processes which have been tentatively applied. The abundant dolomite is used in several of the processes described later.

The preparation of magnesia from sea-water is not new, although it is only recently that it has become industrially important. . . . Oceanic waters contain on an average about 0·14% of magnesium, corresponding to a theoretical yield of 0·34% of the hydroxide. The process is one of simple exchange :—

$$MgCl_2 + Ca(OH)2 \longrightarrow Mg(OH)2 + CaCl_2$$

the relatively insoluble magnesium hydroxide being precipitated. There are, however, other salts present, including calcium bicarbonate and calcium sulphate, and it is necessary to remove a part of these by a preliminary treatment with lime before proceeding to the actual recovery of magnesia. The success of the operation cannot be predicted merely from an examination of the solubility relations, as the velocity of precipitation also plays a part, and when the conditions are right the hydroxide separates before certain impurities such as calcium sulphate, have time to crystallise. The quantities to be handled being so large it is important to cut down the time of settling, etc., as much as possible, and this means a control of *p*H values and temperature to ensure that the hydroxide precipitate is of such particle size and consistence that it will filter

rapidly and not form an impervious sludge. The whole process is an example of a very simple chemical reaction, involving much ingenuity in the planning of its industrial operation.

As the supply may be regarded as inexhaustible, a cubic mile of sea-water containing over four million tons of magnesium, industrial countries having sources of power near to the sea coast have the opportunity of establishing a magnesium industry.

The equation given above represents lime as being the precipitating agent, but by using calcined dolomite—that is, a mixture of calcium and magnesium oxides—the yield is increased by the amount of magnesia already present, so that when true dolomite is used the total yield from a given quantity of sea water is about doubled. At the same time, the magnesia particles, by acting as nuclei for precipitation, affect the physical condition of the precipitate. The choice between the two materials will be determined largely by their local availability.

Processes and Plants

The sea-water process involves the treatment of very large volumes on account of the low concentration of the magnesium salts, but it is simple in principle. The Dead Sea has been proposed as a suitable site for a magnesium industry, the concentration being some eight or ten times greater than in oceanic waters. In considering a site for a plant for this operation the neighbourhood of an estuary or river mouth must be avoided, so that the water taken in has the composition of oceanic water without dilution by fresh water. The exhausted solution after extraction of the magnesia must be discharged at such a distance that it does not reach the intake. By making use of tidal basins these difficulties may be overcome. The earliest American plant was a floating one, but all later plants have been on the coast. A large area is required for the settling tanks and other plant. An installation is operating in this country. The site was originally a small harbour, the entrance to which has not been closed by a caisson. Sufficient storage of water is obtained during high tide to allow the process to continue during the period of low tide. About 10,000,000 gallons of sea-water are used each day, being pumped from the dock into two pre-treatment tanks, in which a little lime is added to react with the dissolved calcium bicarbonate. Calcium carbonate is precipitated, and much of it settles in the tanks, that which is in suspension being removed by sand filters. The filtered water is then ready for the reaction. Calcined dolomite is slaked with water in paddle-type slakers and screened through a 72-mesh screen. The milk thus formed is sprayed on to the surface of the sea-water in large reaction tanks. The manner of mixing the precipitating agent with the water affects the character of the precipitate, and therefore the design of this part of the plant is of importance. The water, bearing magnesium hydroxide in suspension, flows into the settling tank through ports in the centre column. The settling is accelerated by a revolving Dorr thickener, so that the slurry drawn from the tank is of constant concentration. It is pumped to screens and then to heating tanks, where it is heated by steam to facilitate filtering. This is done through cotton vacuum filters, on the outside of which the magnesia forms a cake. The cake falls into a hopper from which it is extruded in fine threads on to a scraper conveyer which feeds it to the rotary kilns, which are similar to those used in cement manufacture, and like them are fired by pulverised coal. The burners are adjustable, and separate combustion chambers are provided, so that the degree of burning may be varied according to the purpose for which the ignited magnesia is required. For the electrolytic production of magnesium a reactive caustic magnesia is preferred, whilst fully calcined material is wanted for the processes of thermal reduction mentioned later. Another plant of the same company makes only dead-burnt magnesia for the refractories industry.

The process used by Messrs. Ocean Salts, Ltd., is similar in general outline, but pure lime is used instead of calcined dolomite as the precipitating agent. In America, the Dow Company constructed a large plant at Freeport, Texas. The site is a narrow peninsula, and the exhausted water is discharged by a canal at a point 7 miles from the intake. In order to avoid dilution by surface water, the intake pipe is 30 ft. below the surface. The lime for precipitation is made from oyster shells, dredged from Galveston Bay, and after washing calcined in rotary kilns with natural gas. The slurry meets the sea-water in rectangular Dorr flocculators through surface weirs, and the mixture is agitated slowly the pH value being electrolytically controlled. Thickeners are used as in the British plant, and the same kind of vacuum filter is employed, but the product is not calcined. Instead, it is dissolved in hydrochloric acid in rubber-lined tanks, the acid being made by burning natural gas in the chlorine produced in the electrolytic cells in the subsequent operation. The magnesium chloride is dehydrated in a series of operations, part of the water being removed by spraying into a gas-fired cylindrical furnace, the next stage being drying in a shelf dryer of the kind used for roasting pyrites, and the last that of heating in rotary kilns after mixing with already dried material in flake form. Whilst other sea-water plants aim at producing magnesium oxide, this process ends with the formation of the anhydrous chloride.

The hydrolysis of the hydrated chloride on heating may be prevented by keeping chlorine ions in excess, and the addition of ammonium chloride to the melt was at one time practised, but is no longer used. The Dow Company in America uses dry hydrogen chloride, which, becoming moist as it removes the hydrate water, is highly corrosive, and involves difficulties in the construction of the plant.

There are thus great advantages in a method which produces the anhydrous chloride in one operation, instead of expelling water from the hydrated salt. This may be done by taking advantage of the reaction between magnesium oxide, carbon, and dry chlorine—

$$MgO + C + Cl_2 = MgCl_2 + CO \text{ and } 2\,MgO + C + 2\,Cl_2 = 2\,MgCl_2 + CO_2.$$

As both reactions are exothermic, the heat required is not great. The ground magnesia is mixed with carbon in the form of coke or anthracite dust and some material for making the mass porous, such as sawdust or peat, and formed into briquettes, which are then heated in a furnace through which there passes a stream of dry chlorine. The anhydrous magnesium chloride is formed in the molten state, and is tapped off at the base of the furnace. One patent of the I.G. Farben dispenses with briquetting and charges lump magnesite and coke into a vertical furnace, the lower part of which is filled with coke alone and into which current is led by two electrodes; the upper electrode is a central vertical tube through which the charge is introduced. The reaction is then confined to the surface of the lumps, and the magnesium chloride as it is formed percolates downwards, exposing fresh surfaces. The briquetting method is more generally used.

Full details of electrolytic practice are not in general available. The process of I. G. Farben, which is in the main followed by Messrs. Magnesium Elektron, uses rectangular steel cells with graphite anodes and iron cathodes, arranged vertically and opposite to one another. The bath of fused salts varies in composition in different works. It usually contains chlorides of the alkali or alkali earth metals as well as magnesium chloride, for the purpose of lowering the melting point and also of lessening its decomposition, which is appreciable when the pure salt is kept molten. Fluorides are also sometimes added. A peculiarity of the process is that on account of the low density of magnesium it floats on the surface, making it necessary to provide for the complete separation of the upper parts of the anode and cathode compartments, in order to prevent contact between the metal, liberated at the cathode, and the chlorine

evolved at the anode. The partitions are of ceramic material immersed from above. Large electrodes are needed, and a correct ratio between their areas and depths of immersion is an important factor. Each cell usually carried 15,000–20,000 amperes, and the potential difference is low, from 7 to 9 volts. The temperature of the bath varies in different works from 670° to 750° C., and the consumption of energy is about 20 kwh. kilogramme of magnesium. The cells are externally heated to keep the bath molten, and from time to time the liquid magnesium is skimmed off and transferred to ladles to the plant for casting into ingots. It is curious to watch the red-hot molten metal being handled with so little burning. Electrolytic magnesium was at one time reputed to corrode very readily on account of entangled hygroscopic chlorides, but with the present-day methods of remelting and casting these salts are eliminated, and a very pure metal is obtained.

The largest magnesium plant in the world is being constructed near Boulder Dam by Basic Magnesium, Ltd., the installation being modelled on the British plant. The magnesia is obtained from Nevada, partly from brucite and partly from magnesite concentrated by flotation. It is calcined and briquetted with Canadian peat moss and chlorinated. An annual output of 56,000 tons is planned, or more than the world output of 1940.

Magnesium being a volatile metal, boiling at 1,097° C., the reduction of the oxide by a non-volatile reducing agent and the removal of the magnesium in the form of a vapour which is then condensed has suggested itself to many inventors, and several processes have become industrially important. The dry oxide is mixed with the reducing agent which may be carbon, calcium carbide, ferro-silicon, aluminium, or certain alloys. As the process is one of distillation the metal is obtained very free from impurities. The presence of even a small proportion of oxide prevents magnesium from forming a homogenous mass on remelting, so that it is necessary to exclude air, which is usually done by working under conditions approaching a vacuum.

Reduction by carbon is, on the face of it, a simple process, but in practice the operation is difficult. The temperature of reduction of magnesia by carbon is high, 2,000° C. or more, and although this may be produced by using a carbon arc, the reaction

$$MgO + C \longleftrightarrow Mg + CO$$

is a reversible one, so that as the vapour cools down the reaction goes from right to left, and the oxide is reformed. Even with an efficient condenser and dilution with an inert gas, the dust obtained is a mixture of the metal and its oxide, difficult or impossible to cast into ingots. The process invented by Hansgirg, and often known as the Radenthein process, from the magnesite-producing district in Austria where the pilot plant was set up, was established in Britain by the Magnesium Metal Corporation, Ltd. It uses briquetted materials in an arc furnace, and the metallic vapour as it is formed is drawn off by suction from a jet of strongly cooled hydrogen. In this way the temperature of the vapour is very quickly brought down to about 200° C., and the reverse reaction is so far suppressed that the condensed dust contains about 90% of metal. The quantity of hydrogen required is very large, and the gas which passes on contains only 1·5% of carbon monoxide. This is converted to the dioxide by mixing with steam and passing through a furnace, the dioxide then being absorbed by water. The hydrogen, after drying, re-enters the process. The condensed magnesium is re-distilled in a separate furnace, still in an atmosphere of hydrogen, passing through a filter on the way to remove suspended particles. It is condensed in a heated vessel, so that it is obtained directly in the liquid form, and is collected in oil from which it is freed by centrifuging when cold.

It is hardly surprising that in this form the process has proved difficult to carry out without accident, and many attempts have been made to simplify it. The plant erected by the Permanente Metals Corporation (one of the undertakings of H. J. Kaiser of shipbuilding fame) in California makes the magnesia into briquettes with petroleum coke and pitch. The furnace is a closed cylinder, lined with carbon blocks, with three-phase arc heating. The first furnace consumes 8,000 kva., but the later units are to be of 12,000. Natural gas, injected through a cooled stainless steel nozzle, is used in place of hydrogen. The cooling chamber has revolving scrapers, and the condensed metal is taken by a screw conveyer to the bin. Electrostatic precipitation is used to increase the average particle size, and the gases are finally filtered through woollen bags. The quantity of natural gas injected is large, being about 25 times that of the gas and vapour produced in the reaction. The condensed dust, which only contains 60 to 65% of magnesium, is pressed into tablets without binding material and charged into electrically heated vertical retorts, in which a high vacuum is maintained. The temperature is stated to be only 750° C., and the metal is condensed in a cooled head and removed for remelting. The plant, which is planned for a very large production, is said to consume a total of 17·8 kwh. per kilogramme of metal of 99·97% purity. Although natural gas avoids some of the dangers of hydrogen, a serious explosion of magnesium dust suspended in air has occurred, and it is evident that there are risks involved in any process in which so oxidisable a metal as magnesium is produced in a finely divided form instead of a compact solid or liquid mass.

Other modifications of the process are being developed in America, the Dow Company using molten lead as the cooling agent, and the Ford Company oil. No particulars are available. In a process devised by the U.S. Bureau of Mines the calcined magnesite is fed down a hollow graphite electrode into the arc furnace and the vapour is quenched by a spray of oil. The condensed magnesium, which is suspended in oil and therefore not liable to the same fire risk, is separated in a centrifugal machine and redistilled. The consumption of current is given as 24–26 kw./kg.

The formation of a gaseous product which can bring about a reverse reaction on cooling is avoided by using other reducing agents in place of carbon. Thus, calcium carbide, used in this country by Messrs. Murex, Ltd., gives only a solid residue. The mixture of magnesia and carbide is heated in vertical gas-fired retorts of heat-resisting steel. A vacuum is maintained, and the metal condenses in a compact form, and not as dust. Calcined dolomite may be used in place of magnesia at the cost only of reducing the yield in proportion to the lime content of the material. The reaction is $MgO + CaC_2 = Mg + CaO + 2C$.

Another reducing agent which has marked advantages is silicon, which is actually used in the form of ferro-silicon. The temperature required is from 1,200° to 1,400°, and the reaction is carried out, as before, in retorts of heat-resisting steel in a good vacuum. The metal condenses in a compact form, ready for remelting. Calcined dolomite may be used, and the reaction is then represented by the equation—

$$2MgO, 2CaO + Si \longrightarrow 2CaO, SiO_2 + 2Mg.$$

The retorts may be heated internally by resistance elements, and the plant is then of a simple character. The process has been used in Germany and in this country, and is now being developed on a large scale in the United States, where ferro-silicon can be produced in sufficient quantity in electric furnaces in scattered plants in eastern industrial regions, where there is a surplus of power. The setting up of plant of this kind makes a new demand on alloy steels, and thus competes with other industries. However, it has been favoured in the United States by the National Academy of Sciences, and plants are being erected by the Dominion Magnesium Company, Union Carbide, Ford, the National Lead Company, and the New England Lime Company aiming at a total annual production of 50,000 short tons.

Retorts for use with either the calcium carbide or the ferro-silicon process, heated inductively by high-frequency current, have been used to a limited extent. The packing

of the charge has to be such that it has a sufficient conductivity to carry the eddy currents which generate the necessary heat.

The process used in this country by Messrs. International Alloys is an interesting application of laboratory experience gained in work with high vacua to operations on a large scale. The magnesia, obtained from sea-water and calcined, is finely ground and mixed with aluminium or an alloy containing aluminium, also finely ground. The mixture, with or without a binding material, is formed into briquettes under pressure and charged into specially designed crucibles, in which it is pre-heated to about 400° C. The crucibles have a downward central outlet which leads to a condenser supported beneath it. The self-contained and portable unit of crucible and condenser, with its pre-heated charge, is raised mechanically through the open bottom of a vertical cylindrical furnace fitted with electrically heated resistance units. The furnace is then sealed, the making of a vacuum-tight joint being one of the features of the plant. The mixture is heated to 1,100°–1,250° C. under a pressure of less than 4 mm. of mercury. The crucible is designed to convey the heat as efficiently as possible to the briquettes and the magnesium, as it is produced by the reduction of the oxide, distils over and is condensed in the water-cooled receiver below the crucible. The vapour condenses to form a mass of very beautiful crystals, and when the temperature has fallen sufficiently the vacuum joint is broken and the condenser unit detached. The mass of metal, which is of high purity, is easily discharged, and only needs to be transferred to a melting furnace from which it is cast into ingots. Another crucible has been heated in the meantime, and takes the place of the first in the vertical furnace. The plant is made up of a number of such cylindrical furnaces.

A new furnace on the same principle has been designed to make the process a continuous one. The furnace is on the plan of the tunnel kilns used in the ceramic industries and in the making of malleable castings. Bogies containing the assemblages of crucible and condenser are propelled through a tunnel which is fitted with electrical resistance heater at the crucible level, whilst the condensers are in a water-cooled zone at the lower level. The design of this furnace embodies integral loading and unloading chambers which are separately evacuated, sealed by specially operated doors. As aluminium swarf and, if necessary, other reducing agents may be used in the process, it is capable of a good deal of elasticity, and the high vacuum ensures that a clean distillate is obtained, free from entangled oxide. That such a plant should be operated successfully is a tribute to the engineering skill of its designers.

Alloy Wrought Irons suitable for making Stay-bolts or Engine Bolts, etc.*

An alloy wrought iron is aggregated from a solidifying mass of pasty particles of highly refined metallic Fe alloyed with Mo, with which, without subsequent fusion, is intentionally incorporated a substantially uniformly distributed quantity of slag in an atmosphere such as is normally present in wrought iron; the alloy containing from about 0·10% to about 1·00% Mo, C less than about 0·06%, with the rest substantially all iron except for the slag and the usual impurities present in wrought iron. The resulting product has a high strength up to about 900° F.

*John W. Davies and Ray McBrian, U.S. 2,286,198, June 16.

A. C. Wickman, Ltd., have sent us a copy of their new catalogue sheet No. W. 43, dealing with the Wickman-Neven Bench Grinding and Lapping Machine GF. 2. This machine has been specially designed for the use of Neven impregnated diamond wheels. It embraces several noteworthy features, and the sheet gives the essential specifications of the machine. Copies may be obtained from A. C. Wickman, Ltd., Tile Hill, Coventry.

"4-6" Molybdenum High-Speed Steel

Various changes have been made in the composition of high-speed steels during the past year or two, and attention has been directed to the use of molybdenum to replace tungsten for this purpose. Several compositions have been recommended, but with few exceptions the application of molybdenum high-speed steels had made little progress in this country prior to the war, with the result that a knowledge of the technique of manufacture and subsequent treatment of the tools was not widespread. One of these exceptions was Darwin's, Ltd., whose "Morex" high-speed steel was developed some time ago and covered by British patent 534,304. This patent covers the "4–6" quality of molybdenum high-speed steel.

In this connection it is noteworthy that a memorandum, recently issued by the High-Speed Steel Association, announced that makers of high-speed steel are ceasing to manufacture the "66" quality of molybdenum high-speed steel, which was introduced as a "substitute" steel; and the "4–6" quality is to be manufactured instead. Experience has shown this quality of steel to be one of the most efficient.

Darwin's, Ltd., placed their patent at the disposal of the Ministry of Supply, when concentration on molybdenum high-speed steels became necessary. No royalties are to be payable during the war period in respect of the manufacture, sale and use of "4–6" steel for Government purposes. But Darwin's, Ltd., go much further in facilitating the successful manufacture and use of this steel. Naturally, this firm, as the patentees, has amassed a great deal of manufacturing experience and data regarding the forging, fabrication, heat-treatment and usage of this type of steel, and they announce that they place this accumulated information freely at the disposal of any user of the steel, whether of its manufacture or use. Comprehensive information on this steel is contained in publication No. 132, copies of which are available on request to Darwin's, Ltd., Fitzwilliam Works, Sheffield.

Beryllium-Copper

The last war stimulated the production and use of aluminium, magnesium, stainless steel, as well as high-speed steel and many other alloys. Amongst the new alloys which the present war will tend to find increased application, under both war and peace conditions, are beryllium-copper alloys. These alloys are corrosion-resistant, non-rusting, non-magnetic, having excellent electrical conductivity, and a tensile strength up to 211,000 lb./in.² An outstanding property is the unusual corrosion-fatigue resistance which has been reported higher by fifty million cycles than the fatigue resistance in air. It has also been found that heat-treated beryllium-copper has a lower degree of creep or elastic hysteresis than the majority of other commercially used alloys. This factor has been responsible for successful applications in the instrument field, thermostatic diaphragms and other control units.

Beryllium-copper alloys in all forms have been produced in commercial quantities in the United States for about eight years. The production of these alloys in this country is a relatively new development. Safety tools from beryllium-copper alloys, for instance, have only recently been manufactured in Great Britain, as well as sheet, wire, rods, and tubes.

Beryllium is produced for ore in the United States, but no metallic beryllium is produced in Britain, though ample supplies of beryl are found within the Empire, particularly in India, South Africa, and Canada. The United States imports the ore from South America and India.

Much useful information on beryllium-copper alloys is given in a booklet prepared by Mr. L. David and published by Beryllium Smelting Co., Ltd., British Unicorn, Ltd., London, E.C. 2.

The Positions of the Carbon Atoms in Martensite*

By N. J. Petch, B.Sc., B.Met.

(Cavendish Laboratory, Cambridge)

It has been found impossible to obtain direct evidence of the positions of the carbon atoms in martensite. Indirect evidence can, however, be obtained from the change in cell dimensions with carbon content and from the fact that the structure is tetragonal. As a result of a study of the subject, the author concludes that the carbon atoms are at the mid-points of the long edges of the martensite tetragonal cell and at the centres of the faces perpendicular to them.

FINK and Campbell[1] first showed that in martensite there are iron atoms on a body-centred tetragonal lattice. An attempt has therefore been made, by annealing at 90° C., to obtain martensite giving sharp X-ray lines. From the intensity of these it might be possible to obtain direct evidence of the carbon positions. Decomposition, however, takes place more readily than line-sharpening. The indirect evidence of the carbon positions has, therefore, to be considered.

Density measurements[2, 3] have eliminated the possibility of carbon replacing iron atoms, and the view most generally held is that the carbon atoms are in the interstices of the iron lattice. There is disagreement, however, about which of the interstices are used. There have been two proposals, one by Hägg,[3] the other by Seljakow, Kurdjumoff and Goodtzow.[4] There are three possible types of interstices. These are at the centres of triangles, tetrahedra or octahedra of iron atoms. With the cell dimensions corresponding to 0% carbon, none of them is large enough to accommodate a carbon atom of radius 0·77 A. without displacement of the neighbouring atoms. As a consequence, with an increase of carbon content there is an increase of cell size. It is not, however, immediately possible to decide where the carbon atoms must be located in order to give the observed dimensions, because with the practical carbon contents only a fraction of the available interstices of any kind can be filled.

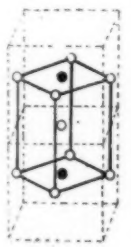


Fig. 1.—The tetragonal representation of austenite.

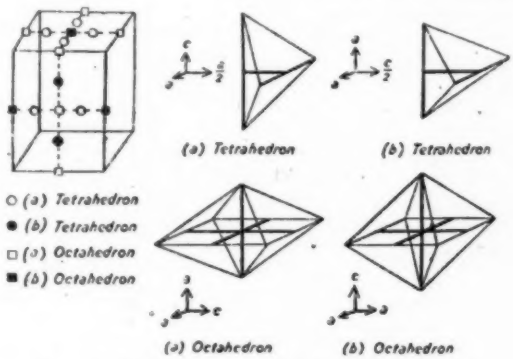


Fig. 2.—The location and dimensions of the interstices in martensite. The axial lengths are shown at the side of each interstice.

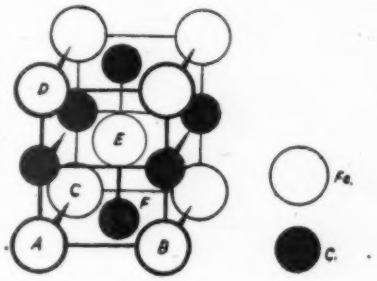


Fig. 3.—The martensite structure.

Seljakow, Kurdjumoff and Goodtzow,[4] however, approaching the question from the relationship between austenite and martensite, considered that the carbon atoms were at the centres of the faces perpendicular to the long axis of the tetragonal cell. The face-centred cubic austenite can be represented as a body-centred tetragonal cell (Fig. 1) They assumed that during the transformation to martensite the identity of the tetragonal cell was retained, while there was adjustment to a smaller axial ratio. They further assumed that in austenite the carbon atoms were at the centres of the face-centred cubes, and that during the martensite transformation they remained in these interstices. These are octahedral interstices in the location that they proposed. They made no mention of the positions at the mid-points of the long edges of the cell, which, actually, are crystallographically equivalent.

The Change in Martensite Dimensions with Carbon Content

Some useful information about the carbon location can be obtained from the change in martensite dimensions with increasing carbon content.

With the dimensions of carbon-free martensite none of the interstices is large enough to accommodate a carbon atom without displacement of the iron atoms. An increase in the size of the interstices used by the carbon is therefore to be expected as the carbon content increases. Consistent measurements of the martensite dimensions have been made by Ohman,[6] Honda and Nishiyama,[2] Hägg[3] and others. The short a axis decreases slightly over the observed range of composition, while the c axis increases more rapidly.

In α-iron all the tetrahedral and all the octahedral interstices are identical, but in martensite the tetragonal structure results in there being two types of tetrahedral interstices and two types of octahedral interstices. The dimensions and location of these are shown in Fig. 2. The

In the analogous case of austenite, the carbon atoms enter the largest interstices.[5] In martensite the triangular interstices are very much smaller than the others and can be neglected. With the dimensions for 0% carbon, in the tetrahedral interstices the distance from the centre to each iron position is 1·60 Å., leaving 0·35 Å. in excess of the iron atomic radius. In the octahedral interstices four of the iron atoms are at a distance which leaves 0·77 Å. excess. The other two, however, leave only 0·18 Å. Assuming atoms to behave as hard spheres, the tetrahedral interstices

* Paper published by the Iron and Steel Institute, February, 1943 (Advance Copy), and reproduced in full.

variation in size of the interstices with change of carbon content is given in Table I.

TABLE I.
THE VARIATION OF THE SIZE OF THE MARTENSITE INTERSTICES WITH CARBON CONTENT.

Centre-Iron Distances, Å. Interstice—												
Tetrahedral (*a*).			Tetrahedral (*b*).			Octahedral (*a*)			Octahedral (*b*).			
No.	0% C.	1·4% C.	No.	0% C.	1·4% C.	No.	0% C.	1·4% C.	No.	0% C.	1·4% C.	
2	1·599	1·587	4	1·599	1·610	2	1·430	1·420	2	1·430	1·517	
2	1·599	1·675				4	2·023	2·078	4	2·023	2·008	

In type (*a*) tetrahedra (Fig. 2) the four iron atoms are all at the same distance from the centre of the interstice when the martensite is carbon-free. In the presence of carbon, however, although two of the centre-iron distances increase, the other two decrease progressively. Accommodation of the carbon atoms at the centre of this type of interstice is, therefore, very unlikely. In type (*b*) tetrahedra the four iron atoms are always equidistant from the centre, and the distance increases with the carbon content. The increase seems too slight, however, to make this location probable.

In the octahedral interstices two of the centre-iron distances are considerably shorter than the other four. Type (*a*) octahedra are eliminated, since the short centre-iron distances decrease progressively as carbon is added. The behaviour of the type (*b*) octahedra is, however, more what would be expected to result from the presence of carbon in them. The short centre iron distances increase rapidly. The fact that the other four centre-iron distances decrease slightly over the observed range of composition is rather unexpected, but not completely unreasonable. These are distances such as AF (Fig. 3), and depend entirely on the separation of A and B, which are held apart by E. In α-iron the distance A F would permit accommodation of a carbon atom at F without pressure on E. It is impossible to predict what secondary adjustments in dimensions would result from displacements of atoms such as E when only a few F positions are filled. There would, however, be a definite tendency for A F to decrease, since the separation of E from A and B is increased. Little decrease would be possible, owing to pressure by the carbon atom on A.

Consideration of the martensite dimensions thus reduces the possible location of the carbon atoms to type (*b*) tetrahedra or type (*b*) octahedra, and the latter appears the more probable.

The Tetragonal Structure of Martensite

It seems possible to make a decision between the octahedral and the tetrahedral interstices from the fact that the martensitic super-saturation of α-iron results in a tetragonal structure.

Seljakow and his co-workers considered that this effect was merely due to the low concentration of carbon. Their argument is as follows: If all the octahedral interstices in α-iron are filled a cubic structure will result. With the practical composition, however, only a fraction of the interstices can be occupied, and, at any instant, there will not be more than one interstice occupied per unit cell. In Fig. 3, with the martensite dimensions, insertion of a carbon atom at F will exert a pressure on the iron atom at the centre of the cell, but not on those at the corners. There will be no other carbon atoms in the unit cell. Thus there will be need for expansion of the cell in the direction AD, but not in the directions at right angles, and a tetragonal structure will result.

This explanation of the tetragonal structure is not satisfactory. If carbon atoms are considered to be randomly distributed amongst a number of unit cells, in some the expansion will be in the direction A D, but in others in the directions A B or A C. X-rays will show the average of these distortions, which will not give a tetragonal structure, but will appear merely as an expansion of the cell, with the retention of the cubic structure. When there is not enough carbon in solution for all the equivalent interstices to be filled, the resultant effect is as if each is partially filled.

The tetragonal structure can be satisfactorily explained in the following manner: In α-iron all the octahedral interstices are equivalent. If all are partially filled a cubic structure results. A tetragonal structure can only be obtained, using the octahedral interstices, if, in spite of their equivalence, a differentiation is made amongst them and only selected ones are utilised by the carbon atoms. If a particular axial direction in the cubic structure is chosen and only the octahedral interstices at the mid-points of the edges parallel to this direction and at the centre of the faces perpendicular to this direction are utilised, a tetragonal structure results. The chosen direction then becomes the *c* axis. The octahedral interstices utilised are of the type (*b*), which, it has been seen above, are satisfactory from the point of view of the change in dimensions with increasing carbon content. Thus, by selective utilisation of the octahedral interstices the tetragonal structure can be obtained.

When, however, the tetrahedral interstices are considered, the tetragonal structure decides against them. Again, in the cubic structure all the tetrahedral interstices are equivalent, and if they were all partially filled the cubic structure would be obtained. It has already been seen that only the (*b*) tetrahedral interstices are possibilities. But no matter how the tetrahedral interstices are selectively filled, the tetragonal structure of the observed type cannot be obtained.

The conclusion from the indirect evidence is, therefore, that the carbon atoms are in the octahedral interstices at the mid-points of the long edges of the martensite tetragonal cell and at the centres of the faces perpendicular to them. These positions are crystallographically equivalent. This structure is shown in Fig. 3. There is never enough carbon in solution for all the positions to be filled. This would require 2·0 carbon atoms per unit cell, whereas, with the observed maximum carbon content, there will be an average of only 0·16 per unit cell. The behaviour is as if, at the most, every interstice was one-twelfth filled.

This structure of martensite has a number of interesting features. Particularly interesting is the question why there is, as a result of supersaturating α-iron, a tetragonal structure at all. Why does the differentiation arise between the octahedral positions, which, from the point of view of α-iron, are completely equivalent? A possibility is that the carbon positions are controlled by the relationship between austenite and martensite. This transformation is almost certainly accomplished by an atomic gliding, during which it is possible that the carbon atoms cannot escape from the interstices that they occupy in austenite. Such a view, however, must remain purely speculative while there is the present lack of an exact knowledge of the atomic mechanism of the austenite-martensite transformation.

Another interesting question is why the octahedral interstices are used instead of the tetrahedral ones, which are larger. It would be a very simple matter for a carbon atom to move from an octahedral position. All that is necessary is that it should move aside from between the two iron atoms most closely pressing upon it. Perhaps the assumption that atoms behave as hard spheres is not always the correct picture. The octahedral interstice, with two short and four long centre-iron distances, may actually be effectively larger for carbon accommodation than the tetrahedral with four medium centre-iron distances.

Other Theories of Martensite

There have been various suggestions, for instance, by Desch[7] and Sauveur,[8] that martensite consists of α-iron with a very fine precipitate of cementite. If, however, there

were actual separation of the cementite, there would be no reason for the tetragonal structure.

In some cases of precipitation, for example $CuAl_2$,[9] an intermediate stage occurs in which there is no actual separation from the parent lattice. Where there is such an association of the lattices, one of the structures may be affected to a certain extent. The normal effect is, however, on the precipitated structure, hence this could not explain the distortion of α-iron into a tetragonal structure, since the α-iron would be the parent lattice. The distortion from the cubic structure could arise if there were carbon atoms partially interstitial in the α-iron, in the plane, common to the cementite and α-iron. It is, however, difficult to see how there could be any such fitting together of the known cementite and martensite lattices. Against any suggestion of cementite formation there is the fact that it implies a certain amount of diffusion of the carbon atoms. This is rather inconsistent with the extreme rapidity of the reaction and its independence of the cooling rate. It is not impossible, however, that, on account of the ease of the tempering action, most martensites contain a certain amount of precipitated cementite.

Honda and Nishiyama[2] have proposed a cubic β-martensite, but strong evidence against this has been put forward by Hägg.[3]

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The Development of Carbide-Tipped Tools

The availability of elements used in the production of carbide cutting materials has involved further developments in manufacture, and the range of materials for this purpose has been widened to permit increased scope of selection for specific purposes. These notes, which refer to developments of Thos. Firth and John Brown, Ltd., may be regarded as a typical example.

THE original experiments with tungsten carbide demonstrated very clearly that this material was to occupy an important place in the field of machining metals. Early development, however, showed that the first carbides were of little use in the machining of any types of steel, for reasons which, at that time, were not apparent. This limiting feature of the early hard metals represented a serious handicap in the development of the use of carbide-tipped tools. As a result of world-wide research the cause of failure of the original tungsten carbide to perform satisfactorily on steel was established, but a complete and satisfactory explanation of the phenomenon has never been forthcoming.

It was observed that these early tools failed by what is now known as "cratering." This phenomenon is due to pressure of the chip on the upper surface of the tool. Where the chip impinges the surface is eroded. This form of cavitation is not unfamiliar to those who have studied the breakdown of high-speed steel tools used for heavy cuts. The "cratering" effect only occurs when turning steel, and the problem, therefore, does not arise when turning cast iron.

This characteristic was eventually overcome by the addition to the early hard metals of one or more of the carbides of titanium, tantalum, niobium and molybdenum. The addition of these carbides certainly prevented the formation of the chip cavity, and as a result such complex carbides would, under certain conditions, work for prolonged periods when cutting steel. They were found, however, to be relatively brittle compared with the normal tungsten carbides previously used. For the successful machining of steel with these alloys conditions had to be good. Fine feeds and high speeds were the order of the day, and only machines in good condition were suitable for the use of such carbide tools.

The Brown-Firth Research Laboratories have carried out exhaustive investigation into this complex system of carbides, and as a result of their work improvements have been incorporated into their "Mitia" brand hard metal, which now offers a grade suitable for almost any set of

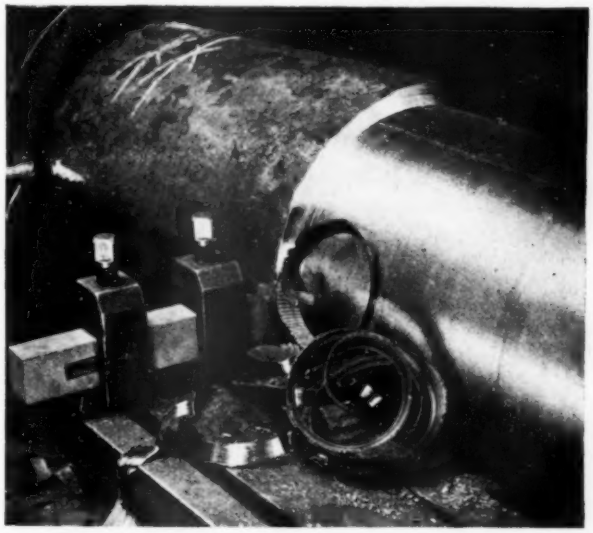

Fig. 1.—Turning large bombs with a newly developed carbide-tipped tool.

conditions. The latest addition to the list is Grade "TA. 5," which may be said to complete the series.

In developing this grade, attention has been paid to producing a material which, while showing the greatest resistance to "cratering," has the strength and toughness to stand up to the arduous conditions which it is designed to meet. In addition, tools of this grade will take a top rake and heavy cuts can then be taken at high speed without the absorption of unduly increased horse-power. Used under ideal conditions, this grade will prove of great value in the rapid machining of heavy forgings, etc. It will possess, too, this great advantage—that it can be successfully used on machines and under conditions where high-speed steel normally would have to be used and with greatly increased tool life.

Speeds and Feeds

The speeds and feeds recommended for Grade "TA. 5" vary considerably, since an outstanding feature of the grade is its ability to operate over a wide range of conditions.

Speed and feed depend upon the quality of the material being cut. For low-carbon steel the speed should be 125–200 ft. per min., while the feed may vary from 0·015 in. up to 0·125 in. per revolution. For steels having a tensile of 40–65 tons the feeds used should be from 0·015 in. to 0·100 in. per revolution. Steels of higher tensile have to be treated more individually, since machinability varies according to the composition, etc., and in these cases advice and assistance as to the suitability of Firth-Brown grades and cutting conditions should be sought.

Examples of Performance

Grade "TA. 5" has been thoroughly tested in various machine shops, including Firth-Brown's own works, and the following examples show the excellent performance of the tools :—

CASE 1.—TURNING LARGE BOMBS.

Material	Alloy steel, machined in 50/60 tons tensile condition
Surface	Extremely bad-forged surface; scale up to $\frac{3}{4}$ in. thick; very irregular in shape.
Roughing operations.—Speed	80 ft. per min.
Feed	0·040 in. per rev.
Depth of cut	Varying from 0 in. to $1\frac{1}{4}$ in.
Tool cut twice along bomb between regrindings—a total distance of 12 ft.	
Diameter	Approx. 15 in.
Semi-finishing operations.—Speed	107 ft. per min.
Feed	0·050 in. per rev.
Depth of cut	steady, between $\frac{3}{4}$ in. and $\frac{7}{8}$ in.

The tool used for the above operation is one specially designed for the work, and in all cases where tools are used for such arduous work the specially developed design will be used. The shank section is 2 in. × $1\frac{1}{2}$ in. The tool works with a 15° top rake, which is, of course, a departure from normal carbide practice and is essential in the use of this grade. The tool, when semi-finishing, is employed with a special form of chip-curler.

CASE 2.—TURNING LARGE FORGINGS.

Size: 20 in. dia., 3 ft. 6 in. long.

Material	Nickel-chrome steel, 65 tons tensile.
Condition	Forged; bad, irregular and scaly surface.
Speed	36 ft. per min. (maximum of machine).
Feed	0·070 in. per rev.
Depth of cut	Averaging $\frac{5}{8}$ in.
Cut for 57 in. (part second cut), withdrawn for reconditioning, but only slightly worn.	

CASE 3.—TURNING LARGE BOMBS.

Material and condition as for Class 1.

Speed	(*a*) 50 ft. per min.; (*b*) 65 ft. per min.
Feed	0·100 in. per rev.
Depth of cut	$1\frac{1}{8}$ in.
Two tools used for test and both capable of machining a complete forging before regrinding.	

It should be clearly understood that in introducing the new grade "TA. 5" it is not suggested that it in any way supersedes the other grades of carbides which this firm manufactures, but is a necessary addition to this already wide range of cutting alloys. Grade "TA. 5" is for use on machines which are normally considered to be suitable only for high-speed steel and where the normal grades of carbide have proved too hard and too brittle for successful use.

It is of particular value in dealing with those numerous jobs which call for a better tool material than high-speed steel, but where the normal grades of carbide cannot, due to the conditions, be applied. On the other hand, where conditions are good then the old-established grades of Firth-Brown carbide should be applied, since their superior hardness and wear resistance will, in such case, allow even greater speeds to be attained, with longer periods between regrinding.

It is useful at this stage to classify the whole range of the Firth-Brown carbide steel-cutting grades in order that the value of each can be properly assessed, showing in what way the grades cover the whole field of the machining of steel. It should be noted that the grades are given in the order of toughness and hardness: the first grade is the toughest, while the last grade is the hardest :—

(1) *Grade* "TA. 5."—A heavy-duty grade for the rough machining of steel under bad conditions. To replace high-speed steel on machines where conditions cannot materially be improved. For machining at relatively low speeds, heavy feeds. For intermittent cutting.

(2) *Grade* "TA."—A general purpose grade for machining steel under normal conditions on machines where reasonably good conditions are maintained. Will, however, satisfactorily rough-machine forgings, etc., but has not the shock resistance of Grade "TA. 5," and will not withstand the abuse for which this latter grade ("TA. 5") is designed. Grade "TA" is particularly suitable for the machining of alloy steel bar and forgings.

(3) *Grade* "TE. 10."—A grade harder and more wear-resistant than Grade "TA," which may be used for rough machining under very good conditions or for finish machining where conditions, particularly machine conditions, are not as good as they might be. Particularly useful on mild steels and low alloy steels. This grade has proved to be especially effective for the machining of shells on modern shell-turning lathes.

(4) *Grade* "TE."—For finish turning all classes of steel. Conditions should be good and fine feeds employed. It is possible to use extremely high speeds with this grade, due to its extreme hardness and wear resistance.

As stated, Grades "TA. 5," "TA," "TE. 10," and "TE" are designed for cutting steel. The series is completed by Grades "A," "B," "C," and "D. 1," designed for machining cast iron, non-ferrous metals, glass, pottery, synthetic substances, etc.

Surface Protection of Aircraft by Means of Paints and Lacquers

ANODISING, according to Jaeger*, though attractive from the weight standpoint, produces a relatively rough surface even when lacquer is applied. Modern acryl lacquers weigh 80 g. per sq. metre for the usual single coat. As two or three coats may be necessary to obtain the essential smoothness on anodised material, the author suggests that anodising should be reserved for those structural members for which surface friction is not critical. When comparing methods of protection, increased frictional drag may be more important than added weight.

X-Ray Crystal Analysis in Works Control

MESSRS. ADAM HILGER, LTD., 98, St. Pancras Way, Camden Road, London, N.W. 1, have published an informative booklet designed to make clear to practical metallurgists that the use of X-ray crystal analysis methods can, in their hands, give extremely useful information, and that a suitably designed apparatus may be used as a works tool for the control of manufacturing processes and for routine inspection. The examination may, in general, be conducted in a simple and non-destructive way on objects unprepared except for acid etching. In some cases the method provides a control which hitherto has not been available and in others a more rapid and comprehensive routine test than is at present in use.

The aim in view is not a fundamental addition to knowledge, but to co-relate the behaviour of a specimen with that of a similar specimen of known quality by comparing their X-ray diffraction patterns. Although this method has proved to be of outstanding value for the examination of metals, so far it has been little applied to the control of manufacturing operations.

Several examples of its applications are given: its general scope may be summarised as: (1) Checking quality on receipt of raw material for uniformity of physical condition: (2) Control of fabrication processes, such as hot-rolling, cold-rolling, drawing, extrusion, stamping and pressing, forging, and machining: (3) control of heat-treatment, such as annealing for strain release, grain size control, tempering: (4) control of finishing processes, such as electroplating, oxide and other protective coatings: (5) checking quality of parts in service for fatiguing.

* W. Jaeger, *Der Flieger*, xxi, 1942, No. 1. (*H.D.A. Bull.*, viii, October 17, 1942, No. 7, p. 274.)

The Problem of Copper and Galvanised Iron in the Same Water System

By L. Kenworthy, M.Sc., A.R.C.S.

Premature failure of galvanised hot-water tanks connected to copper circulating pipes in domestic systems led to laboratory investigation and to an extensive examination of service installations. Rapid failures were found to be due not to direct electrolytic action, but to very slight dissolution of copper by the circulating water, severe corrosion following the subsequent deposition of this copper on the galvanised coating. The salient features of the investigation of this problem are given together with the author's conclusions.

SOME years ago it was suggested that the practice of installing hot-water systems in which copper circulating pipes are connected to galvanised hot tanks or cylinders was deleterious to the life of the galvanised hot-water container. A number of premature failures of hot-water tanks in domestic systems led to a laboratory investigation and to an extensive examination of service installations, which are described by Mr. Kenworthy.*

On theoretical grounds there appeared to be some justification for the suggestion. In the first place, trouble might be caused owing to the very slight but definite solvent action of certain waters on copper, since the copper taken into solution might be deposited on the galvanised coating. This would give rise to numbers of short-circuited electro-chemical cells, the deposited copper acting as cathode and the surrounding zinc as anode. Secondly, direct electrolytic action might occur; this would be detrimental to the zinc, being the less noble metal, although in normally hard waters one would expect the action to be partially stifled after a time by the formation of a protective scale.

The preliminary examination of certain bi-metal installations *in situ* gave very strong indications that in some cases copper circulating pipes did accelerate the corrosion of galvanised hot-water containers to which they were connected. On the other hand, it must be emphasised that other instances were discovered where no harm had resulted from such a combination. It seemed desirable, therefore, to undertake a thorough investigation of the problem, with a view to determining the conditions favourable and unfavourable to this bi-metal type of installation.

After briefly reviewing previous work on this problem, the author refers to practical experience, and states that of the cases of premature failure of galvanised tanks or cylinders connected to copper pipes which it was possible to investigate fully, two provided exceptionally valuable information. The first of these concerned houses on two estates erected by the same builder at about the same period, operating on the same water supply, and equipped with identical hot-water systems, except that on one estate galvanised tanks had been fitted with copper pipes and on the other with galvanised pipes. Of the 1,000 installations on the estate fitted with copper pipes, 50% had failed in four years, whereas on the other, which consisted of 50 houses, no failures had occurred at the time of inspection, which was six years after the houses had been erected. The second case concerned two neighbouring estates, both in this instance being equipped with identical copper pipes—galvanised tank installations, but operating on different water supplies. On one estate every installation failed in four years, whereas on the other no failure had been experienced in ten years. On investigation, it was found that samples of hot circulating water taken from the estate where trouble had occurred possessed an average copper content of 0·032 part/10^5, whilst corresponding samples from the other estate contained only 0·003 part/10^5. The reason for this difference, presumably due to the different capacity of the two supply waters to dissolve copper, was confirmed by the fact that free carbon dioxide† (which largely governs cupro-solvency) was present to the extent of 0·41 part/10^5 in the water supplying the estate where failures occurred, whereas the water on the other estate only contained 0·11 part/10^5.

With regard to the investigation of other cases of premature failure, 41 samples of water were analysed; the carbon dioxide content of these ranged from 0·3 to 3·6 parts/10^5, whilst only 11 samples contained less than 0·5 part/10^5.

Occasionally, copper installations were found to have influenced the life of the galvanised cold-storage cisterns. This was sometimes recorded with extremely aggressive cupro-solvent waters where copper service pipes were installed. More usually, however, it was the result of badly designed installations, in which the cold cisterns were placed so close to the hot containers that a considerable amount of back circulation took place. All the cases of this nature investigated were confined to all-copper hot systems (i.e., copper pipes and copper hot cylinders) in which the copper content of the circulating water often reaches a relatively high value.

There was no evidence in any of the cases examined that increased corrosion of galvanised iron was caused by direct electrolytic stimulation. For example, no localisation of corrosion near the copper pipes was observed, nor, on insulating the pipes from the container, could any electrical potential difference be detected. It appeared, therefore, as a result of this practical survey that any increased corrosion of galvanised components of water installations brought about as a result of using copper pipes was almost entirely due to extremely small amounts of copper dissolved by the water and subsequently deposited on the galvanised coatings. In fact, in some cases the amount of copper which had been deposited on the inside of a container was so great as to be readily detected visually.

In order to determine to what extent small amounts of copper in solution affected the attack of zinc and galvanised iron, preliminary laboratory experiments were carried out in stagnant solutions. Although demonstrating the fundamental principles underlying this problem, such tests are far removed from those prevailing in service, and it was, therefore, considered essential for further tests to be conducted in which service conditions were produced on a laboratory scale. For this purpose, small-scale circulating systems were constructed and experiments were carried out to determine the effect of hot circulating water containing copper (up to 0·03 part/10^5) on the corrosion of galvanised iron, and also the effect of hot water circulating through copper pipes on the corrosion of galvanised iron.

It is interesting to note that, in the experiments using copper-containing water, the ratio of copper removed from solution by circulation over the galvanised specimens to that originally present, increased with increase in the

* L. Kenworthy, *Jour. Inst. Metals*, Feb., 1943, pp. 67–90.

† The free carbon dioxide of a water is estimated by titration with sodium carbonate, using phenolphthalein as an indicator. Throughout this report the term "free carbon dioxide content" is based upon this assumption and should not be confused with the term "aggressive" carbon dioxide, which is used by some investigators to describe the carbon dioxide in excess of that necessary to maintain in solution the calcium bicarbonate present in any particular water.

amount originally present. The increased attack of the galvanised iron, however, bore an approximately constant ratio to the amount of copper removed from solution. Results in a third series of experiments indicated clearly that the weight of metal attacked was greater in circulators fitted with copper pipes.

The obvious solution of this problem is to avoid the construction of hot-water installations composed partly of galvanised iron and partly of copper, in this investigation, however, consideration has been given to the possibility of eliminating or minimising the rapid attack of galvanised coating which may occur in such installations.

The results of this extensive investigation have led the author to the following conclusions :—

(1) The presence of small amounts of copper in a natural water causes increased corrosion of zinc or galvanised iron with which the water comes in contact ; even 0·01 part of copper/10^5 can cause a seriously increased attack. The severity of the attack at the lower concentrations (up to about 0·03 part/10^5) is almost directly proportional to the amount of copper in the water, but as the concentration rises (at least up to 1 part/10^5), further increase in copper causes relatively less increased attack.

(2) The mechanism of the reaction which takes place when zinc or galvanised iron is immersed in very dilute solutions of copper (less than 1 part/10^5) consists in the deposition of small particles of metallic copper on the zinc or galvanised iron which stimulate corrosion by setting up numbers of short-circuited electro-chemical cells, the deposited copper particles acting as cathodes and the surrounding zinc as anodes. The reaction is clearly not one of simple replacement (as it is with more concentrated solutions), since the loss in weight of the zinc or galvanised iron is many times greater than the weight of copper removed from the solution.

(3) As a result of laboratory experiments and from the investigation of installations in service, it has been established that with certain types of public supply water a small but sufficient amoubt of copper to cause increased attack of zinc or galvanised iron can be dissolved by hot or cold water circulating or passing through copper pipes. The amount of copper dissolved is not sufficient to affect in any way the " serviceability " of the copper pipes.

(4) The amount of copper dissolved varies with the nature of the water, depending largely on its carbon dioxide content and temporary hardness. Increase in the carbon dioxide content increases the amount of copper dissolved, thereby causing enhanced corrosion of zinc or galvanised iron. Conversely, increase in temporary hardness tends to decrease cupro-solvency, and, from this point of view, hard waters would seem to be less dangerous in systems composed partly of copper and partly of galvanised iron. On the other hand, in hard waters the presence of copper tends to induce a pitting form of attack on galvanised iron, so that unless the ratio of temporary hardness to carbon dioxide content is sufficiently high almost to prevent cupro-solvency, enough copper may go into a solution to set up severe local attack. Hence, for a given degree of cupro-solvency, more rapid penetration of galvanised iron is probable with hard than with soft water.

(5) In view of the importance of such factors as design and operating conditions of installations, it is difficult to draw a sharp line of demarcation between those waters which are unsafe and those which are quite suitable to use in systems composed partly of copper and partly of galvanised iron. It would appear, however, that the use of waters containing more than 0·2 part/10^5 of carbon dioxide (irrespective of hardness) is generally inadvisable.

(6) In water systems employing both copper and galvanised-iron components, any increased corrosion of the galvanised iron due to the copper is almost entirely to be attributed to small amounts of copper dissolved by the water ; the direct electrolytic effect of contact between dissimilar metals plays a very minor part.

(7) A general tendency has been noted for the copper content of water passing over copper to fall with time (particularly in hard waters), presumably owing to the formation of a protective scale. There are also indications of a fall in the rate of corrosion of zinc with time, and this effect seems to be partly independent of the amount of copper in the water. It follows that in water systems composed partly of galvanised iron and partly of copper, the greatest damage to the galvanised parts of the system is liable to occur in the early stages of the life of the installation.

(8) The most obvious way out of the difficulty is the use of all-copper or all-galvanised hot-water systems. Where this is not possible, cupro-solvency may be considerably reduced by suitable water treatment. For hard waters aeration (by cascading) is recommended ; for softer waters lime additions serve the double purpose of increasing temporary hardness and absorbing free carbon dioxide.

(9) Where the measures indicated under (8) above cannot be applied, other possible remedial measures fall into two classes. First, prevention or reduction of copper dissolution, and second, extraction of any copper dissolved by the water before it can deposit on the galvanised iron. The following methods for minimising copper dissolution have met with considerable success in the laboratory, though it is not suggested that each method is necessarily applicable in practice.

(*a*) The maintenance of a very small concentration of zinc salts (either chloride or sulphate) in the water ; 0·05 part/10^5 (expressed as zinc) appears to be about the optimum concentration, but the evidence is not sufficient to quote a figure with any certainty. The effect does not persist, so that reduction in copper dissolution ceases immediately the addition of zinc salts is discontinued.

(*b*) Cathodic protection of the copper by contact with metallic zinc ; the degree of protection diminishes with increasing distance from the point of contact, and it is therefore essential that contacts with zinc are not too distantly spaced. In copper piping the insertion of small 3-in. lengths of galvanised piping at not more than 10 ft. intervals would provide a fair degree of protection, although closer zinc insertions would be an advantage. The success of this method depends partly on the formation of zinc salts as described in (*a*) above.

(*c*) The use of pre-treated aluminium-brass tubing, which retains the desirable features of copper as regards appearance and ease of fitting, but which results in much less copper dissolution.

10. Laboratory tests have also indicated that reduction in the copper concentration of water before it comes into contact with the sides of the galvanised hot-water container may be successfully carried out by the use of a filter (consisting of a receptacle packed with zinc turnings), placed in the container over the flow-pipe entrance. Patent protection is being sought for remedial measures based on these principles.

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